INSTITUTION

OF

MECHANICAL ENGINEERS.

ESTABLISHED 1847.

PROCEEDINGS.

38767
25/2/97.

1895.

PARTS 1–2.

PUBLISHED BY THE INSTITUTION,
19 VICTORIA STREET, WESTMINSTER, S.W.

CONTENTS.

1895.

PARTS 1–2.

PAST-PRESIDENTS.

George Stephenson, 1847–48. (*Deceased* 1848.)

Robert Stephenson, F.R.S., 1849–53. (*Deceased* 1859.)

Sir William Fairbairn, Bart., LL.D., F.R.S., 1854–55. (*Deceased* 1874.)

Sir Joseph Whitworth, Bart., D.C.L., LL.D., F.R.S., 1856–57, 1866. (*Deceased* 1887.)

John Penn, F.R.S., 1858–59, 1867–68. (*Deceased* 1878.)

James Kennedy, 1860. (*Deceased* 1886.)

The Right Hon. Lord Armstrong, C.B., D.C.L., LL.D., F.R.S., 1861–62, 1869.

Robert Napier, 1863–65. (*Deceased* 1876.)

John Ramsbottom, 1870–71.

Sir William Siemens, D.C.L., LL.D., F.R.S., 1872–73. (*Deceased* 1883.)

Sir Frederick J. Bramwell, Bart., D.C.L., LL.D., F.R.S., 1874–75.

Thomas Hawksley, F.R.S., 1876–77. (*Deceased* 1893.)

John Robinson, 1878–79.

Edward A. Cowper, 1880–81. (*Deceased* 1893.)

Percy G. B. Westmacott, 1882–83.

Sir Lowthian Bell, Bart., F.R.S., 1884.

Jeremiah Head, 1885–86.

Sir Edward H. Carbutt, Bart., 1887–88.

Charles Cochrane, 1889.

Joseph Tomlinson, 1890–91. (*Deceased* 1894.)

William Anderson, C.B., D.C.L., F.R.S., 1892–93.

Institution of Mechanical Engineers.

OFFICERS.

1895.

PRESIDENT.

Alexander B. W. Kennedy, LL.D., F.R.S., ... London.

PAST-PRESIDENTS.

William Anderson, C.B., D.C.L., F.R.S., ... Woolwich.
The Rt. Hon. Lord Armstrong, C.B., D.C.L., LL.D., F.R.S., Newcastle-on-Tyne.
Sir Lowthian Bell, Bart., F.R.S., ... Northallerton.
Sir Frederick J. Bramwell, Bart., D.C.L., LL.D., F.R.S., London.
Sir Edward H. Carbutt, Bart., ... London.
Charles Cochrane, ... Stourbridge.
Jeremiah Head, ... London.
John Ramsbottom, ... Alderley Edge.
John Robinson, ... Leek.
Percy G. B. Westmacott, ... Newcastle-on-Tyne.

VICE-PRESIDENTS.

Sir Douglas Galton, K.C.B., D.C.L., F.R.S., ... London.
Samuel W. Johnson, ... Derby.
Edward P. Martin, ... Dowlais.
Sir James Ramsden, ... Barrow-in-Furness.
E. Windsor Richards, ... Low Moor.
J. Hartley Wicksteed, ... Leeds.

MEMBERS OF COUNCIL.

John A. F. Aspinall, ... Horwich.
William Dean, ... Swindon.
Benjamin A. Dobson, ... Bolton.
Bryan Donkin, ... London.
John Hopkinson, Jun., D.Sc., F.R.S., ... London.
Arthur Keen, ... Birmingham.
William Laird, ... Birkenhead.
John G. Mair-Rumley, ... London.
Francis C. Marshall, ... Newcastle-on-Tyne.
Henry D. Marshall, ... Gainsborough.
William H. Maw, ... London.
James Platt, ... Gloucester.
T. Hurry Riches, ... Cardiff.
A. Tannett Walker, ... Leeds.
Sir William H. White, K.C.B., LL.D., F.R.S., ... London.

TREASURER.

Harry Lee Millar.

SECRETARY.

Alfred Bache,
Institution of Mechanical Engineers, 19 *Victoria Street, Westminster, S.W.*
[Telegraphic address:—*Mech, London.* Telephone, 3264.]

THE INSTITUTION OF MECHANICAL ENGINEERS.

Memorandum of Association.

August 1878.

1st. The name of the Association is "The Institution of Mechanical Engineers."

2nd. The Registered Office of the Association will be situate in England.

3rd. The objects for which the Association is established are:—

(a.) To promote the science and practice of Mechanical Engineering and all branches of mechanical construction, and to give an impulse to inventions likely to be useful to the Members of the Institution and to the community at large.

(b.) To enable Mechanical Engineers to meet and to correspond, and to facilitate the interchange of ideas respecting improvements in the various branches of mechanical science, and the publication and communication of information on such subjects.

(c.) To acquire and dispose of property for the purposes aforesaid.

(d.) To do all other things incidental or conducive to the attainment of the above objects or any of them.

4th. The income and property of the Association, from whatever source derived, shall be applied solely towards the promotion of the objects of the Association as set forth in this Memorandum of Association, and no portion thereof shall be paid or transferred directly or indirectly, by way of dividend, bonus, or otherwise howsoever, by way of profit to the persons who at any time are or have been Members of the Association, or to any of them, or to any person claiming through any of them: Provided that nothing herein contained shall prevent the payment in good faith of remuneration to any officers or servants of the Association, or to any Member of the Association, or other person, in return for any services rendered to the Association, or prevent the giving of privileges to the Members of the Association in attending the meetings of the Association, or prevent the borrowing of money (under such powers as the Association and the Council thereof may possess) from any Member of the Association, at a rate of interest not greater than five per cent. per annum.

5th. The fourth paragraph of this Memorandum is a condition on which a licence is granted by the Board of Trade to the Association in pursuance of Section 23 of the Companies Act 1867. For the purpose of preventing any evasion of the terms of the said fourth paragraph, the Board of Trade may from time to time, on the application of any Member of the Association, impose further conditions, which shall be duly observed by the Association.

6th. If the Association act in contravention of the fourth paragraph of this Memorandum, or of any such further conditions, the liability of every Member of the Council shall be unlimited; and the liability of every Member of the Association who has received any such dividend, bonus, or other profit as aforesaid, shall likewise be unlimited.

7th. Every Member of the Association undertakes to contribute to the Assets of the Association in the event of the same being wound up during the time that he is a Member, or within one

year afterwards, for payment of the debts and liabilities of the Association contracted before the time at which he ceases to be a Member, and of the costs, charges, and expenses for winding up the same, and for the adjustment of the rights of the contributories amongst themselves, such amount as may be required not exceeding Five Shillings, or in case of his liability becoming unlimited such other amount as may be required in pursuance of the last preceding paragraph of this Memorandum.

8th. If upon the winding up or dissolution of the Association there remains, after the satisfaction of all its debts and liabilities, any property whatsoever, the same shall not be paid to or distributed among the Members of the Association, but shall be given or transferred to some other Institution or Institutions having objects similar to the objects of the Association, to be determined by the Members of the Association at or before the time of dissolution; or in default thereof, by such Judge of the High Court of Justice as may have or acquire jurisdiction in the matter.

Articles of Association.

February 1893.

INTRODUCTION.

Whereas an Association called "The Institution of Mechanical Engineers" existed from 1847 to 1878 for objects similar to the objects expressed in the Memorandum of Association of the Association (hereinafter called "the Institution") to which these Articles apply;

And whereas the Institution was formed in 1878 for furthering and extending the objects of the former Institution, by a registered Association, under the Companies Acts 1862 and 1867;

And whereas terms used in these Articles are intended to have the same respective meanings as they have when used in those Acts, and words implying the singular number are intended to include the plural number, and *vice versâ*;

Now therefore it is hereby agreed as follows:—

CONSTITUTION.

1. For the purpose of registration the number of members of the Institution is unlimited.

MEMBERS, ASSOCIATE MEMBERS, GRADUATES, ASSOCIATES, AND HONORARY LIFE MEMBERS.

2. The present Members of the Institution, and such other persons as shall be admitted in accordance with these Articles, and none others, shall be Members of the Institution, and be entered on the register as such.

3. Any person may become a Member of the Institution who shall be qualified and elected as hereinafter mentioned, and shall agree to become such Member, and shall pay the entrance fee and first subscription accordingly.

4. The qualification of Members shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

5. The election of Members shall be conducted as prescribed by the By-laws from time to time in force, as provided by the Articles.

6. In addition to the persons already admitted as Graduates, Associates, and Honorary Life Members respectively, the Institution may admit such persons as may be qualified and elected in that behalf as Associate Members, Graduates, Associates, and Honorary Life Members respectively of the Institution, and may confer upon them such privileges as shall be prescribed by the By-laws from time to time in force, as provided by the Articles: provided that no Associate Member, Graduate, Associate, or Honorary Life Member shall be deemed to be a Member within the meaning of the Articles.

7. The qualification and mode of election of Associate Members, Graduates, Associates, and Honorary Life Members shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

8. The rights and privileges of every Member, Associate Member, Graduate, Associate, or Honorary Life Member shall be personal to himself, and shall not be transferable or transmissible by his own act or by operation of law.

ENTRANCE FEES AND SUBSCRIPTIONS.

9. The Entrance Fees and Subscriptions of Members, Associate Members, Graduates, and Associates shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

EXPULSION.

10. If any Member, Associate Member, Graduate, or Associate shall leave his subscription in arrear for two years, and shall fail to pay such arrears within three months after a written application has been sent to him by the Secretary, his name may be struck off the register by the Council at any time afterwards, and he shall thereupon cease to have any rights as a Member, Associate Member, Graduate, or Associate, but he shall nevertheless continue liable to pay the arrears of subscription due at the time of his name being so struck off: provided always that this regulation shall not be construed to compel the Council to remove any name, if they shall be satisfied the same ought to be retained.

11. The Council may refuse to continue to receive the subscriptions of any person who shall have wilfully acted in contravention of the regulations of the Institution, or who shall in the opinion of the Council have been guilty of such conduct as shall have rendered him unfit to continue to belong to the Institution; and may remove his name from the register, and he shall thereupon cease to be a Member, Associate Member, Graduate, or Associate (as the case may be) of the Institution.

GENERAL MEETINGS.

12. The General Meetings shall consist of the Ordinary Meetings, the Annual General Meeting, and of Special Meetings as hereinafter defined.

13. The Annual General Meeting shall take place in London in one of the first four months of every year. The Ordinary Meetings shall take place at such times and places as the Council shall determine.

14. A Special Meeting may be convened at any time by the Council, and shall be convened by them whenever a requisition signed by twenty Members or Associate Members of the Institution,

specifying the object of the Meeting, is left with the Secretary. If for fourteen days after the delivery of such requisition a Meeting be not convened in accordance therewith, the Requisitionists or any twenty Members or Associate Members of the Institution may convene a Special Meeting in accordance with the requisition. All Special Meetings shall be held in London.

15. Seven clear days' notice of every Meeting, specifying generally the nature of any special business to be transacted at any Meeting, shall be given to every person on the register of the Institution, except as provided by Article 35, and no other special business shall be transacted at such Meeting; but the non-receipt of such notice shall not invalidate the proceedings of such Meeting. No notice of the business to be transacted (other than such ballot lists as may be requisite in case of elections) shall be required in the absence of special business.

16. Special business shall include all business for transaction at a Special Meeting, and all business for transaction at every other Meeting, with the exception of the reading and confirmation of the Minutes of the previous Meeting, the election of Members, Associate Members, Graduates, and Associates, and the reading and discussion of communications as prescribed by the By-laws, or by any regulations of the Council made in accordance with the By-laws.

PROCEEDINGS AT GENERAL MEETINGS.

17. Twenty Members or Associate Members shall constitute a quorum for the purpose of a Meeting other than a Special Meeting. Thirty Members or Associate Members shall constitute a quorum for the purpose of a Special Meeting.

18. If within thirty minutes after the time fixed for holding the Meeting a quorum is not present, the Meeting shall be dissolved, and all matters which might, if a quorum had been present, have been done at a Meeting (other than a Special Meeting) so dissolved, may forthwith be done on behalf of the Meeting by the Council.

19. The President shall be Chairman at every Meeting, and in his absence one of the Vice-Presidents; and in the absence of all Vice-Presidents a Member of Council shall take the chair; and if no Member of Council be present and willing to take the chair, the Meeting shall elect a Chairman.

20. The decision of a General Meeting shall be ascertained by show of hands, unless, after the show of hands, a poll is forthwith demanded; and by a poll, when a poll is thus demanded. The manner of taking a show of hands or a poll shall be in the discretion of the Chairman; and an entry in the Minutes, signed by the Chairman, shall be sufficient evidence of the decision of the General Meeting. Each Member and Associate Member shall have one vote and no more. In case of equality of votes the Chairman shall have a second or casting vote: provided that this Article shall not interfere with the provisions of the By-laws as to election by ballot.

21. The acceptance or rejection of votes by the Chairman shall be conclusive for the purpose of the decision of the matter in respect of which the votes are tendered: provided that the Chairman may review his decision at the same Meeting, if any error be then pointed out to him.

BY-LAWS.

22. The By-laws set forth in the schedule to these Articles, and such altered and additional By-laws as shall be substituted or added as hereinafter mentioned, shall regulate all matters by the Articles left to be prescribed by the By-laws, and all matters which consistently with the Articles shall be made the subject of By-laws. Alterations in, and additions to, the By-laws, may be made only by resolution of the Members and Associate Members at an Annual General Meeting, after notice of the proposed alteration or addition has been announced at the previous Ordinary Meeting, and not otherwise.

COUNCIL.

23. The Council of the Institution shall be chosen from the Members only, and shall consist of one President, six Vice-Presidents, fifteen ordinary Members of Council, and of the Past-Presidents. The President, two Vice-Presidents, and five Members of Council (other than Past-Presidents), shall retire at each Annual General Meeting, but shall be eligible for re-election. The Vice-Presidents and Members of Council to retire each year shall, unless the Council agree among themselves, be chosen from those who have been longest in office, and in cases of equal seniority shall be determined by ballot.

24. The election of a President, Vice-Presidents, and Members of Council, to supply the place of those retiring at the Annual General Meeting, shall be conducted in such manner as shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

25. The Council may supply any casual vacancy in the Council (including any casual vacancy in the office of President) which shall occur between one Annual General Meeting and another; and the President, Vice-Presidents, or Members of Council so appointed by the Council shall retire at the succeeding Annual General Meeting. Vacancies not filled up at any such Meeting shall be deemed to be casual vacancies within the meaning of this Article.

OFFICERS.

26. The Treasurer, Secretary, and other employés of the Institution shall be appointed and removed in the manner prescribed by the By-laws from time to time in force, as provided by the Articles. Subject to the express provisions of the By-laws, the officers and servants of the Institution shall be appointed and removed by the Council.

27. The powers and duties of the officers of the Institution shall, subject to any express provision in the By-laws, be determined by the Council.

POWERS AND PROCEDURE OF COUNCIL.

28. The Council may regulate their own procedure, and delegate any of their powers and discretions to any one or more of their body, and may determine their own quorum: if no other number is prescribed, three members of Council shall form a quorum.

29. The Council shall manage the property, proceedings, and affairs of the Institution, in accordance with the By-laws from time to time in force.

30. The Treasurer may, with the consent of the Council, invest in the name of the Institution any moneys not immediately required for the purposes of the Institution in or upon any of the following investments (that is to say):—

(A) The Public Funds, or Government Stocks of the United Kingdom, or of any Foreign or Colonial Government guaranteed by the Government of the United Kingdom.

(B) Real or Leasehold Securities, or in the purchase of real or leasehold properties in Great Britain or Ireland.

(C) Debentures, Debenture Stock, or Guaranteed or Preference Stock, of any Company incorporated by special Act of Parliament, the ordinary Shareholders whereof shall at the time of such investment be in actual receipt of half-yearly or yearly dividends.

(D) Stocks, Shares, Debentures, or Debenture Stock of any Railway, Canal, or other Company, the undertaking whereof is leased to any Railway Company at a fixed or fixed minimum rent.

(E) Stocks, Shares, or Debentures of any East Indian Railway or other Company, which shall receive a contribution from Her Majesty's East Indian Government of a fixed annual percentage on their capital, or be guaranteed a fixed annual dividend by the same Government.

(F) The security of rates levied by any corporate body empowered to borrow money on the security of rates, where such borrowing has been duly authorised by Act of Parliament.

31. The Council may, with the authority of a resolution of the Members and Associate Members in General Meeting, borrow moneys for the purposes of the Institution on the security of the property of the Institution, or otherwise at their discretion.

32. No act done by the Council, whether *ultra vires* or not, which shall receive the express or implied sanction of the Members and Associate Members in General Meeting, shall be afterwards impeached by any member of the Institution on any ground whatsoever, but shall be deemed to be an act of the Institution.

NOTICES.

33. A notice may be served by the Council upon any Member, Associate Member, Graduate, Associate, or Honorary Life Member, either personally or by sending it through the post in a prepaid letter addressed to him at his registered place of abode.

34. Any notice, if served by post, shall be deemed to have been served at the time when the letter containing the same would be delivered in the ordinary course of the post; and in proving such service it shall be sufficient to prove that the letter containing the notice was properly addressed and put into the post office.

35. No Member, Associate Member, Graduate, Associate, or Honorary Life Member, not having a registered address within the United Kingdom, shall be entitled to any notice; and all proceedings may be had and taken without notice to such member, in the same manner as if he had had due notice.

By-laws.

(*Last Revision, February* 1894.)

MEMBERSHIP.

1. Candidates for admission as Members must be persons not under twenty-five years of age, who, having occupied during a sufficient period a responsible position in connection with the practice or science of Engineering, may be considered by the Council to be qualified for election.

2. Candidates for admission as Associate Members must be persons not under twenty-five years of age, who, being engaged in such work as is connected with the practice or science of Engineering, may be considered by the Council to be qualified for election, though not yet to occupy positions of sufficient responsibility, or otherwise not yet to be eligible, for admission as Members. They may afterwards be transferred at the discretion of the Council to the class of Members.

3. Candidates for admission as Graduates must be persons holding subordinate situations, and not under eighteen years of age. They must furnish evidence of training in the principles as well as in the practice of Engineering. Before attaining the age of twenty-six years, those elected after 1892 must apply for election as Members, Associate Members, or Associates, if they desire to remain connected with the Institution; they may not continue Graduates after attaining the age of twenty-six.

4. Candidates for admission as Associates must be persons not under twenty-five years of age, who from their scientific attainments or position in society may be considered eligible by the Council. They may afterwards be transferred at the discretion of the Council to the class of Associate Members or of Members.

5. The Council shall have the power to nominate as Honorary Life Members persons of eminent scientific acquirements, who in their opinion are eligible for that position.

6. The Members, Associate Members, Graduates, Associates, and Honorary Life Members shall have notice of and the privilege to attend all Meetings; but Members and Associate Members only shall be entitled to vote thereat.

7. The abbreviated distinctive Titles for indicating the connection with the Institution of Members, Associate Members, Graduates, Associates, or Honorary Life Members thereof, shall be the following:—for Members, M. I. Mech. E.; for Associate Members, A. M. I. Mech. E.; for Graduates, G. I. Mech. E.; for Associates, A. I. Mech. E.; for Honorary Life Members, Hon. M. I. Mech. E.

8. Subject to such regulations as the Council may from time to time prescribe, any Member, Associate Member, or Associate may upon application to the Secretary obtain a Certificate of his membership or other connection with the Institution. Every such certificate shall remain the property of, and shall on demand be returned to, the Institution.

ENTRANCE FEES AND SUBSCRIPTIONS.

9. Each Member shall pay an Annual Subscription of £3, and on election an Entrance Fee of £2.

10. Each Associate Member shall pay an Annual Subscription of £2 10*s*., and on election an Entrance Fee of £1. If afterwards transferred by the Council to the class of Members, he shall pay on transference 10*s*. additional subscription for the current year, and £1 additional entrance fee.

11. Each Graduate shall pay an Annual Subscription of £1 10*s*., but no Entrance Fee. Any Graduate elected prior to 1893, if transferred by the Council to the class of Associate Members, shall pay on transference £1 additional subscription for the current year, but no additional entrance fee; if transferred direct to the class of Members, he shall pay on transference £1 10*s*. additional subscription for the current year, and £1 additional entrance fee.

12. Each Associate shall pay an Annual Subscription of £2 10*s.*, and on election an Entrance Fee of £1. If afterwards transferred by the Council to the class of Associate Members, he shall pay on transference no additional subscription or entrance fee. If transferred direct to the class of Members, he shall pay on transference 10*s.* additional subscription for the current year, and £1 additional entrance fee; except Associates elected prior to 1893, who shall pay no additional entrance fee on transference.

13. All subscriptions shall be payable in advance, and shall become due on the 1st day of January in each year; and the first subscription of Members, Associate Members, Graduates, and Associates, shall date from the 1st day of January in the year of their election.

14. In the case of Members, Associate Members, Graduates, or Associates, elected in the last three months of any year, the first subscription shall cover both the year of election and the succeeding year.

15. Any Member, Associate Member, or Associate, whose subscription is not in arrear, may at any time compound for his subscription for the current and all future years by the payment of Fifty Pounds, if paid in any one of the first five years of his membership. If paid subsequently, the sum of Fifty Pounds shall be reduced by One Pound per annum for every year of membership after five years. All compositions shall be deemed to be capital moneys of the Institution.

16. The Council may at their discretion reduce or remit the annual subscription, or the arrears of annual subscription, of any Member or Associate Member who shall have been a subscribing member of the Institution for twenty years, and shall have become unable to continue the annual subscription provided by these By-laws.

17. No Proceedings or Ballot Lists or Certificates shall be sent to Members, Associate Members, Graduates, or Associates, who are in

arrear with their subscriptions more than twelve months, and whose subscriptions have not been remitted by the Council as hereinbefore provided.

ELECTION OF MEMBERS, ASSOCIATE MEMBERS, GRADUATES, AND ASSOCIATES.

18. A recommendation for admission according to Form A or B in the Appendix shall be forwarded to the Secretary, and by him be laid before the next Meeting of the Council. The recommendation must be signed by not less than five Members or Associate Members if the application be for admission as a Member or Associate Member or Associate, and by three Members or Associate Members if it be for a Graduate.

19. All elections shall take place by ballot, four-fifths of the votes given being necessary for election.

20. All applications for admission shall be communicated by the Secretary to the Council for their approval previous to being inserted in the ballot list for election, and the approved ballot list shall be signed by the President and forwarded to the Members and Associate Members. The name of any Candidate approved by the Council for admission as an Associate Member or an Associate shall not be inserted in the ballot list until he has signed the Form C in the Appendix. The ballot list shall specify the name, occupation, and address of the Candidates, and also by whom proposed and seconded. The lists shall be opened only in the presence of the Council on the day of election, by a Committee to be appointed for that purpose.

21. The Elections shall take place at the General Meetings only.

22. When the proposed Candidate is elected, the Secretary shall give him notice thereof according to Form D; but his name shall not be added to the register of the Institution until he shall have paid his Entrance Fee and first Annual Subscription, and signed the Form E in the Appendix.

23. In case of non-election, no mention thereof shall be made in the Minutes, nor any notice given to the unsuccessful Candidate.

24. An Associate Member desirous of being transferred to the class of Members, or an Associate to the class of Associate Members or of Members, shall forward to the Secretary a recommendation according to Form F in the Appendix, signed by not less than five Members or Associate Members, which shall be laid before the next meeting of Council for their approval. On their approval being given, the Secretary shall notify the same to the Candidate according to Form G; but his name shall not be added to the list of Members or Associate Members until he shall have signed the Form H, and shall have paid the additional entrance fee (if any), and the additional subscription (if any) for the current year.

ELECTION OF PRESIDENT, VICE-PRESIDENTS, AND MEMBERS OF COUNCIL.

25. Candidates shall be put in nomination at the General Meeting preceding the Annual General Meeting, when the Council are to present a list of their retiring Members who offer themselves for re-election; any Member or Associate Member shall then be entitled to add to the list of Candidates. The ballot list of the proposed names shall be forwarded to the Members and Associate Members. The ballot lists shall be opened only in the presence of the Council on the day of election, by a Committee to be appointed for that purpose.

APPOINTMENT AND DUTIES OF OFFICERS.

26. The Treasurer shall be a Banker, and shall hold the uninvested funds of the Institution, except the moneys in the hands of the Secretary for current expenses. He shall be appointed by the Members and Associate Members at a General or Special Meeting, and shall hold office at the pleasure of the Council.

27. The Secretary of the Institution shall be appointed, as and when a vacancy occurs, by the Members and Associate Members at a General or Special Meeting, and shall be removable by the Council upon six months' notice from any day. The Secretary shall give the same notice. The Secretary shall devote the whole of his time to the work of the Institution, and shall not engage in any other business or profession.

28. It shall be the duty of the Secretary, under the direction of the Council, to conduct the correspondence of the Institution; to attend all meetings of the Institution, and of the Council, and of Committees; to take minutes of the proceedings of such meetings; to read the minutes of the preceding meetings, and all communications that he may be ordered to read; to superintend the publication of such papers as the Council may direct; to have the charge of the library; to direct the collection of the subscriptions, and the preparation of the account of expenditure of the funds; and to present all accounts to the Council for inspection and approval. He shall also engage (subject to the approval of the Council) and be responsible for all persons employed under him, and set them their portions of work and duties. He shall conduct the ordinary business of the Institution, in accordance with the Articles and By-laws and the directions of the President and Council; and shall refer to the President in any matters of difficulty or importance, requiring immediate decision.

MISCELLANEOUS.

29. All Papers shall be submitted to the Council for approval, and after their approval shall be read by the Secretary at the General Meetings, or by the Author with the consent of the Council; or, if so directed by the Council, shall be printed in the Proceedings without having been read at a General Meeting.

30. All books, drawings, communications, &c., shall be accessible to the members of the Institution at all reasonable times.

31. All communications to the Meetings shall be the property of the Institution, and be published only by the authority of the Council.

32. None of the property of the Institution—books, drawings, &c.—shall be taken out of the premises of the Institution without the consent of the Council.

33. All donations to the Institution shall be enumerated in the Annual Report of the Council presented to the Annual General Meeting.

34. The General Meetings shall be conducted as far as practicable in the following order:—

1st. The Chair to be taken at such hour as the Council may direct from time to time.

2nd. The Minutes of the previous Meeting to be read by the Secretary, and, after being approved as correct, to be signed by the Chairman.

3rd. The Ballot Lists, previously opened by the Council, to be presented to the Meeting, and the new Members, Associate Members, Graduates, and Associates elected to be announced.

4th. Papers approved by the Council to be read by the Secretary, or by the Author with the consent of the Council.

35. Each Member or Associate Member shall have the privilege of introducing one friend to any of the Meetings; but, during such portion of any meeting as may be devoted to any business connected with the management of the Institution, visitors shall be requested by the Chairman to withdraw, if any Member or Associate Member asks that this shall be done.

36. Every Member, Associate Member, Graduate, Associate, or Visitor, shall write his name and residence in a book to be kept for the purpose, on entering each Meeting.

37. The President shall ex officio be member of all Committees of Council.

38. Seven clear days' notice at least shall be given of every meeting of the Council. Such notice shall specify generally the business to be transacted by the meeting. No business involving the expenditure of the funds of the Institution (except by way of payment of current salaries and accounts) shall be transacted at any Council meeting unless specified in the notice convening the meeting.

39. The Council shall present the yearly accounts to the Annual General Meeting, after being audited by a professional accountant, who shall be appointed annually by the Members and Associate Members at a General or a Special Meeting, at a remuneration to be then fixed by the Members and Associate Members.

40. Any member wishing to have a copy of the Papers sent to him for consideration beforehand can do so by sending in his name once in each year to the Secretary; and a copy of all Papers shall then be forwarded to him as early as possible prior to the date of the Meeting at which they are intended to be read.

41. At any Meeting of the Institution any member shall be at liberty to re-open the discussion upon any Paper which has been read or discussed at the preceding Meeting; provided that he signifies his intention to the Secretary at least one month previously to the Meeting, and that the Council decide to include it in the notice of the Meeting as part of the business to be transacted.

APPENDIX.

FORM A.

Mr. being years of age, and desirous of admission into the Institution of Mechanical Engineers, we, the undersigned proposer and seconder from our personal knowledge, and the three other signers from trustworthy information, propose and recommend him as a proper person to belong to the Institution.

Witness our hands, this day of

Members or Associate Members.

FORM B.

Mr. born on being desirous of admission into the Institution of Mechanical Engineers, we, the undersigned proposer and seconder from our personal knowledge, and the other signer or signers from trustworthy information, propose and recommend him as a proper person to become a Graduate thereof.

Witness our hands, this day of

Members or Associate Members.

FORM C.

If elected an of the Institution of Mechanical Engineers, I, the undersigned, do hereby engage to ratify my election by signing the form of agreement and paying the entrance fee and annual subscription in conformity with the By-laws.

Witness my hand, this day of

FORM D.

Sir,—I have to inform you that on the you were elected a of the Institution of Mechanical Engineers. For the ratification of your election in conformity with the rules, it is requisite that the enclosed form be returned to me with your signature, and that your Entrance Fee and first Annual Subscription be paid, the amounts of which are and respectively. If these be not received within two months from the present date, the election will become void.

I am, Sir, Your obedient servant,

Secretary.

FORM E.

I, the undersigned, being elected a of the Institution of Mechanical Engineers, do hereby agree that I will be governed by the regulations of the said Institution, as they are now formed or as they may hereafter be altered; that I will advance the objects of the Institution as far as shall be in my power, and will attend the Meetings thereof as often as I conveniently can: provided that, whenever I shall signify in writing to the Secretary that I am desirous of withdrawing from the Institution, I shall (after the payment of any arrears which may be due by me at that period) be free from this obligation.

Witness my hand, this day of

FORM F.

Mr. being years of age, and desirous of being transferred into the class of . of the Institution of Mechanical Engineers, we, the undersigned, from our personal knowledge recommend him as a proper person to be so transferred by the Council.

Witness our hands, this day of

Members or Associate Members.

FORM G.

Sir,—I have to inform you that the Council have approved of your being transferred to the class of of the Institution of Mechanical Engineers. For the ratification of your transference in conformity with the rules, it is requisite that the enclosed form be returned to me with your signature, and that your additional Entrance Fee and additional Annual Subscription for the current year be paid, the amounts of which are and respectively. If these be not received within two months from the present date, the transference will become void.

I am, Sir, Your obedient servant,

Secretary.

FORM H.

I, the undersigned, having been transferred to the class of of the Institution of Mechanical Engineers, do hereby agree that I will be governed by the regulations of the said Institution, as they now exist, or as they may hereafter be altered; that I will advance the objects of the Institution as far as shall be in my power, and will attend the Meetings thereof as often as I conveniently can: provided that, whenever I shall signify in writing to the Secretary that I am desirous of withdrawing from the Institution, I shall (after the payment of any arrears which may be due by me at that period) be free from this obligation.

Witness my hand, this day of

Institution of Mechanical Engineers.

PROCEEDINGS.

JANUARY 1895.

The FORTY-EIGHTH ANNUAL GENERAL MEETING of the Institution was held in the rooms of the Institution of Civil Engineers, London, on Thursday, 31st January 1895, at Half-past Seven o'clock p.m.; Professor ALEXANDER B. W. KENNEDY, LL.D., F.R.S., President, in the chair.

The Minutes of the previous Meeting were read, approved, and signed by the President.

The PRESIDENT announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and that the following thirty-one candidates were found to be duly elected:—

MEMBERS.

ASHCROFT, ANDREW GEORGE, . .	London.
BEARD, BERNARD, ...	Garston.
BERCHEM, ALPHONSE HENRY EMANUEL,	London.
BOORMAN, JOSEPH ASHWORTH, . .	Leeds.
CORNER, JOHN FREDERICK, . .	Manchester.
GRIFFITHS, HARRY DENIS, . .	Johannesburg.
JACKSON, ROBERT CATTLEY, . .	Newcastle-on-Tyne.
JAMES, CHRISTOPHER WILLIAM, . .	Leeds.
WORDINGHAM, CHARLES HENRY, . .	Manchester.
WYLIE, JOHN CONDIE, . . .	Axim, Gold Coast.

ASSOCIATE MEMBERS.

Blaxter, Augustus Pearce, Jun.,	London.
Burn, George Francis,	Bradford.
Haines, Charles James,	Otterbourne.
Horner, Joseph Gregory,	Bath.
Larard, Charles Edward,	London.
Moore, Thomas Lamb,	Belfast.
Parkinson, Hudson Clough,	Bristol.
Penn, William Cooper,	London.
Pullar, Albert Evans,	Perth.
West, Charles Herbert,	Liverpool.
Wort, Walter Edward,	East Cowes.

ASSOCIATE.

Docker, Frank Dudley,	Birmingham.

GRADUATES.

Alcock, Alfred Edwin,	Sheffield.
Dresser, Charles,	London.
Fryer, Tom Jefferson,	Glasgow.
Gallé, William Alexandré,	Manchester.
Keen, Harry A.,	Birmingham.
Marriner, John,	London.
Read, George Henry,	London.
Wilkin, Ernest Vivian,	Wallsend.
Yeames, James Lamb,	Belfast.

The following Annual Report of the Council was then read:—

ANNUAL REPORT OF THE COUNCIL.

1895.

The present is the Forty-Eighth Annual General Meeting of the Institution; and the Council submit the following Report to the Members upon the business of the past year, dealing with the several subjects in the same order as on previous occasions.

At the end of last year the number of names in all classes on the roll of the Institution was 2,222, as compared with 2,157 at the end of the previous year, showing a net gain of 65. During 1894 there were added to the register 153 names; against which the loss by decease was 31, and by resignation or removal 57.

During 1894 the following distinctions have been conferred by the Queen upon Members of this Institution. In connection with the opening of the Manchester Ship Canal by Her Majesty, Sir William H. Bailey, Mayor of Salford, and Sir E. Leader Williams, Engineer-in-Chief of the Canal, have received the honour of knighthood. Sir T. Salter Pyne, Engineer to H.H. the Ameer of Afghanistan, has received the honour of knighthood and a Companionship of the Star of India. Mr. J. Wolfe Barry, Engineer of the Tower Bridge, and Mr. W. H. Preece, Engineer-in-Chief and Electrician to the Post Office, have been made Companions of the Bath. To each gentleman the Council have had the pleasure of offering their congratulations on behalf of the Institution.

The following twelve Transferences have been made by the Council in 1894:—

To the class of Members.

Allen, Francis,	Graduate	Alexandria.
Birkett, Herbert,	do.	London.
Bocquet, Harry Claude,	do.	Tucuman.
Budenberg, Christian Frederick,	do.	Manchester.
Hill, John Kershaw,	do.	Walton-on-Thames.
Tangye, Harold Lincoln,	do.	Birmingham.

To the class of Associate Members.

NASMITH, JOSEPH,	Associate	Manchester.
DAVIDSON, ALBERT,	Graduate	Sheffield.
EDGCOME, JAMES EDMUND,	do.	Kingston-on-Thames.
FLETCHER, JOSEPH ERNST,	do.	Sheffield.
WILLIS, EDWARD TURNLEY,	do.	London.
WINMILL, HALLETT,	do.	Johannesburg.

The following twenty-four Deceases of Members of the Institution have occurred during the past year:—

BATTLE, ARTHUR EDWIN,	Melbourne.
BOOTH, WILLIAM STANWAY,	Dublin.
COULSON, WILLIAM,	Thirsk.
CROSS, JAMES,	Widnes.
GILKES, EDGAR,	Grange-over-Sands.
GUILFORD, FRANCIS LEAVER,	Nottingham.
HARRIS, JOHN HENRY,	London.
HARVEY, EDWARD CARTWRIGHT,	Johannesburg.
HICK, JOHN,	Whalley.
KENNEDY, THOMAS STUART,	Wetherby.
LESLIE, ANDREW,	Newcastle-on-Tyne.
LOW, GEORGE,	Ipswich.
MATTOS, ANTONIO GOMES DE,	Rio de Janeiro.
MIDELTON, THOMAS,	Sydney.
PROSSER, WILLIAM HENRY,	London.
RAVENHILL, JOHN RICHARD,	Uxbridge.
REID, JAMES,	Glasgow.
SHARDLOW, AMBROSE,	Sheffield.
TAYLOR, THOMAS ALBERT OAKES,	Leeds.
TOMLINSON, JOSEPH,	London.
TREW, JAMES BRADFORD,	Watford.
WALKER, WILLIAM,	London.
WILLMAN, CHARLES,	Middlesbrough.
YATES, HENRY,	Brantford, Ontario.

Of these Mr. Gilkes was a Member of the Institution from 1856, and a Member of Council from 1868 to 1875. Mr. Hick was an original Member of the Institution on its formation in 1847, a Member of Council in 1872–3, and a Vice-President from 1874 to 1876. Mr. Tomlinson was a Member of the Institution from 1857, and having been for many years a Member of Council and a Vice-President he occupied the Presidential chair in 1890 and 1891.

The following twenty-seven gentlemen have ceased to be Members of the Institution during the past year:—

Baillie, Robert,	London.
Baillie, Robert Alexander,	London.
Baraclough, William Henry,	Birmingham.
Barstow, Thomas Hulme (Graduate),	Dargaville, N.Z.
Boughton, Henry Francis,	Sheffield.
Carlyle, Lieut. Thomas, R.A.,	Singapore.
Cornes, Cornelius,	London.
Esson, David Duncan,	London.
Evans, Joseph,	Wolverhampton.
Goodger, Walter William,	Nottingham.
Goodwin, Arnold, Jun.,	London.
Greening, William Alfred,	London.
Hosking, Thomas,	London.
Jewell, Henry William,	Winchester.
Macbrair, William Maxwell,	Sheffield.
Perry, Edwin (Associate),	Newcastle-on-Tyne.
Phillips, Henry Parnham,	Lahore.
Pirrie, Norman,	London.
Rodrigues, José Maria de Chermont,	Rio de Janeiro.
Scott, George Innes,	Newcastle-on-Tyne.
Stuart-Hartland, Dare Arthur,	Calcutta.
Sturgeon, John,	Croydon.
Suverkrop, John Peter,	Harriman, U.S.
Swale, Gerald (Graduate),	Wiarton, Ontario.
Walkeden, George Henry,	Melbourne.
Winkfield, Richard Ernest (Graduate),	London.
Yates, Herbert Rushton,	Pontiac, U.S.

In addition to these there have been thirty Resignations of membership.

The Accounts for the year ending 31 December 1894 are now submitted to the Members (*see* pages 10–13), after having been passed by the Finance Committee, and certified by Mr. Robert A. McLean, chartered accountant, the auditor appointed by the Members at the last Annual General Meeting. The receipts during the year were £7,081 3*s.* 2*d.*, while the expenditure, actual and estimated, was £5,292 16*s.* 10*d.*, leaving a balance of receipts over expenditure of £1,788 6*s.* 4*d.* The financial position of the Institution at the

end of the year is shown by the balance sheet: the total investments and other assets amount to £39,135 15s. 9d.; and allowing £600 for accounts owing but not yet rendered, the capital of the Institution amounts to £38,535 15s. 9d., of which the greater part, as seen from the balance sheet, is invested in Railway Debenture Stocks, registered in the name of the Institution. The certificates of the whole of the securities have been duly audited by the Finance Committee and the auditor.

At the last Annual General Meeting the results of the Marine-Engine Trials carried out by the Research Committee under the chairmanship of the President were summarised and reviewed by Professor Beare in an elaborate paper, which gave rise to a long discussion. A noteworthy feature of the latter was the presentation by Capt. Sankey, for the first time in so thoroughly practical a form, of the thermodynamic principles previously elaborated before this Institution by Mr. J. Macfarlane Gray, and their graphic application to the data furnished by these trials. The excellent illustrations, so clearly worked out and explained, can hardly fail to prove of great permanent value in drawing attention to the high practical importance of these principles, and in facilitating the use of the entropy diagram as an important help in the investigation of the working of steam engines regarded as heat engines.

The Research Committee on the Value of the Steam-Jacket, under the chairmanship of Mr. Henry Davey, have prepared a third report, which is being made ready for publication in the Institution Proceedings, comprising several experiments conducted under ordinary conditions of working, through the kind assistance of those who have been able to offer steam engines for the purpose. Before concluding their research, the Committee have determined to undertake a series of laboratory experiments, with a specially constructed apparatus, for the purpose of endeavouring to ascertain, approximately at least, the laws which govern steam-cylinder condensation. It is hoped that the results of such experiments, together with the practical information already obtained, may enable the present research to be brought to a useful issue.

The Experiments upon the use of Ropes and Belts for the Transmission of Power, announced a year ago as about to be undertaken by the Société Industrielle du Nord de la France at Lille, have been carried out during the past year. On behalf of this Institution they have been attended by Professor Capper, by whom the Report of the Committee when finally settled will be translated into English, and will be accompanied by an independent account of his own observations at the trials, with a view to the discussion of this important subject at a meeting of the Institution.

As a Memorial of the late Mr. P. W. Willans, who as a Member of this and other kindred institutions did so much to promote the advancement of engineering science and practice, a fund was raised during last year by a number of his friends, for the purpose of awarding triennially or at longer intervals a premium for the best original paper on such a general subject as the utilization or transformation of energy, treated especially from the point of view of efficiency or economy. The Council of this Institution, jointly with the Council of the Institution of Electrical Engineers, are the trustees of the fund; and the premium will be awarded alternately by each Council for such a paper communicated to their Institution, unless no paper of sufficient merit in their judgment shall have been so communicated since their preceding award. The first award will be made in December 1897 by the Institution of Electrical Engineers.

The Library of the Institution has received by presentation and exchange during the past year the additions enumerated in pages 14–22, for which the Council here record their thanks to the several Donors. Members who have published works valuable for reference, or original pamphlets on engineering subjects, or records of experiments, of which they could present copies, are reminded that such contributions to the Library are acceptable for permanent preservation.

The General Meetings in 1894 were the Annual General Meeting and the Spring Meeting, both held in London; the Summer Meeting

in Manchester; and the Autumn Meeting in London. Altogether eight sittings were occupied in the reading and discussion of ten of the following Papers, which are published in the Proceedings:—

Research Committee on Marine-Engine Trials: Abstract of results of Experiments on Six Steamers, and Conclusions drawn therefrom in regard to the efficiency of Marine Boilers and Engines; by Professor T. Hudson Beare, F.R.S.E.

On the Surface Condensation of Steam; by Lt.-Colonel Thomas English.

Address by the President, Professor Alexander B. W. Kennedy, LL.D., F.R.S.

Description of the Grafton High-Speed Steam-Engine; by Mr. Edward W. Anderson.

Description of a Fluid-Pressure Reversing Gear for Locomotive Engines; by Mr. David Joy.

Description of the new Electric Lighting Works, Manchester; by Dr. John Hopkinson, F.R.S.

Electric Welding; by Mr. Benjamin Alfred Dobson.

Description of Twin Screw-Propellers with Adjustable Immersion, fitted on Canal Boats; by Mr. Henry Barcroft.

Description of the Manchester Main Drainage Works; by Mr. William Thomas Olive.

The Manufacture of Standard Screws for Machine-made Watches; by Mr. Charles J. Hewitt.

Drilling Machines for Cylindrical Boiler Shells; by Mr. Samuel Dixon.

Third Report of the Research Committee on the Value of the Steam-Jacket. Mr. Henry Davey, Chairman.

The attendances during 1894 were as follows:—at the Annual General Meeting 109 Members and 108 Visitors; at the Spring Meeting 100 Members and 116 Visitors; at the Summer Meeting 330 Members and 60 Visitors; and at the Autumn Meeting 81 Members and 47 Visitors.

The Summer Meeting, held again in Manchester after an interval of nineteen years, was as largely attended as might be expected in an engineering centre of such magnitude and importance, which moreover has given their professional training to so many former and present Members of the Institution in all parts of the world. Last year was indeed rendered peculiarly eventful in that locality by the practical consummation of so many new engineering undertakings, calculated to influence in a high degree the prosperity of the city and district. The Ship Canal, having been visited by the Members

three years previously when in course of construction and prior to the admission of the water, was now seen with the water in; and some of the principal mechanical appliances for the working of the traffic were pointed out by Sir E. Leader Williams in the visit kindly arranged by him. The Electric Lighting Station, the Hydraulic Power Works, the Main Drainage Works, and the Gas Works, all carried out by the municipality, were the objects of other visits, in addition to the large number of engineering, manufacturing, warehousing, and other establishments opened to inspection. The Electric Lighting Station and the Main Drainage Works formed themselves the subjects of two of the papers contributed for reading and discussion at the meeting. The Council of the Owens College kindly invited the Members to hold their meeting in the College; the Lord Mayor of Manchester honoured them with a reception at his Conversazione in the Town Hall; and the Local Members entertained them with a gala performance at the theatre. They were also received with the utmost hospitality at the various Works which they were invited to visit in Oldham, Bury, Rochdale, Bolton, and Prescot, and at the locomotive works of the Lancashire and Yorkshire Railway at Horwich, and those of the London and North Western Railway at Crewe; while for the facilities afforded for these various excursions they were further indebted to the Directors of the Lancashire and Yorkshire and the London and North Western Railway.

In recognition of the admirable arrangements made for the convenience and enjoyment of the Members, the Council have had the pleasure of presenting on behalf of the Institution to Mr. Charles Hopkinson, in appreciation of his valued services as Honorary Secretary for the Meeting, a bronze statuette of Mr. Hamo Thornycroft's beautiful work "The Mower." It is mounted upon a pedestal bearing an inscription to the above effect.

In accordance with the Rules of the Institution, the President, two Vice-Presidents, and six Members of Council, retire from office this day. The result of the ballot for the election of the Council for the present year will be announced to the Meeting.

Dr. ACCOUNT OF EXPENDITURE AND RECEIPTS

Expenditure.	£	s.	d.	£	s.	d.
To Printing and Engraving Proceedings of 1894	1,019	5	8			
,, Reprinting former Proceedings	93	9	0			
	1,112	14	8			
Less Authors' Copies of Papers, repaid	15	14	0	1,097	0	8
,, Stationery and General Printing				190	1	4
,, Binding				34	4	3
,, Rent				710	0	0
,, Salaries and Wages				2,067	13	0
,, Coal, Firewood, and Lighting				46	12	4
,, Fittings and Repairs				29	4	8
,, Postages, Telegrams, and Telephone				268	0	4
,, Insurance				7	0	6
,, Law Charges				13	15	8
,, Petty Expenses				45	17	1
,, Meeting Expenses—						
Printing	171	14	3			
Reporting	52	11	0			
Diagrams, Screen, &c.	110	9	9			
Travelling and Incidental Expenses	145	16	10	480	11	10
,, Dinner Guests				47	15	11
,, Research				244	14	7
,, Books purchased				10	4	8
				5,292	16	10
Accounts owing, not yet rendered, say	600	0	0			
Less Reserve in previous year for accounts since paid	600	0	0	0	0	0
Balance, being excess of Receipts over Expenditure, carried down				1,788	6	4
				£7,081	3	2

	£	s.	d.
To Investment—			
£1,780 6s. *India 3% Stock*	1,771	9	6
Cash Balance 31st December 1894	2,692	15	9
	£4,464	5	3

FOR THE YEAR ENDING 31st DECEMBER 1894. *Cr.*

Receipts.	£	s.	d.	£	s.	d.
By Entrance Fees—						
78 *New Members at £2*	156	0	0			
48 *New Associate Members at £1*	48	0	0			
2 *New Associates at £1*	2	0	0			
6 *Graduates transferred to Members at £1*	6	0	0	212	0	0
„ Subscriptions for 1894—						
1649 *Members at £3*	4,947	0	0			
71 *Associate Members at £2 10s.*	177	10	0			
65 *Associates at £2 10s.*	162	10	0			
144 *Graduates at £1 10s.*	216	0	0			
6 *Graduates transferred to Members at £1 10s.*	9	0	0			
5 *Graduates transferred to Associate Members at £1*	5	0	0	5,517	0	0
„ Subscriptions in arrear—						
77 *Members at £3*	231	0	0			
1 *Member, instalment*	0	6	0			
1 *Associate Member at £2 10s.*	2	10	0			
1 *Associate at £3*	3	0	0			
1 *Associate at £2 10s.*	2	10	0			
3 *Graduates at £2*	6	0	0			
12 *Graduates at £1 10s.*	18	0	0	263	6	0
„ Subscriptions in advance—						
24 *Members at £3*	72	0	0			
1 *Associate Member at £2 10s.*	2	10	0			
5 *Graduates at £1 10s.*	7	10	0	82	0	0
„ Interest—						
From Investments	856	19	5			
From Whitworth Bequest	73	18	1			
From Bank	22	17	2	953	14	8
„ Reports of Proceedings—						
Extra Copies sold				53	2	6
				£7,081	3	2

	£	s.	d.
By Balance brought down	1,788	6	4
By Life Compositions, 7 Members	188	0	0
Cash Balance 31st December 1893	2,487	18	11
	£4,464	5	3

Dr. BALANCE SHEET

	£	s.	d.
To Sundry Creditors—			
Accounts owing, not yet rendered, say	600	0	0
Capital of the Institution at this date . . . . (exclusive of back numbers of Proceedings, which cost £4,900)	38,535	15	9
	£39,135	15	9

Signed by the following members of the Finance Committee:—

ALEXANDER B. W. KENNEDY,

JEREMIAH HEAD, | JOHN G. MAIR-RUMLEY,

DOUGLAS GALTON, | WILLIAM H. MAW.

AS AT 31ST DECEMBER 1894. *Cr.*

	£	s.	d.	£	s.	d.	£	s.	d.
By Cash—*In Union Bank, on Deposit*				1,800	0	0			
„ „ „ *on Current account* . .				392	15	9			
In London Joint Stock Bank	332	13	7						
In hand { *expended since closing accounts* }	167	6	5	500	0	0	2,692	15	9
„ Investments—(*cost* £26,558 5*s.* 9*d.*)									
£ 2,200 *North Eastern Railway* 4% *Debenture Stock*									
1,800 *Great Western* „ „ „ „									
2,244 *Great Eastern* „ „ „ „									
2,755 *Metropolitan* „ „ „ „									
2,325 „ „ $3\frac{1}{2}$% „ „									
1,000 *Aire and Calder Navigation* „ „ „									
4,237 *London and North Western Ry.* 3% „ „									
3,288 *Midland Railway* „ „ „									
2,450 *Taff Vale* „ „ „ „									
4,053 *India Stock* „ „ „									
700 *Sir J. Whitworth and Co., Ld.* 5% „ „									
Two hundred £10 shares Sir J. Whitworth and Co., Ld.									
The Market Value of these investments at 31st Dec. 1894 was about . .							34,510	0	0
„ Subscriptions in Arrear, probable value							250	0	0
„ Office Furniture and Fittings							343	0	0
„ Library							1,240	0	0
„ Drawings, Engravings, Models, Specimens, and Sculpture .							100	0	0
„ Proceedings, back numbers, cost £4,900									
							£39,135	15	9

Audited and Certified by

ROBERT A. McLEAN, F.C.A.,

Auditor,

1 Queen Victoria Street, London, E.C.

LIST OF DONATIONS TO LIBRARY.

Blast-Furnace Practice at Ormesby Iron Works, Middlesbrough, by Charles Cochrane; from the author.

Surveying and Surveying Instruments, by G. A. T. Middleton; from the author.

Lancashire Watch Company, its rise and progress; from Mr. Charles J. Hewitt.

Manual of Naval Architecture, third edition 1894, by Dr. W. H. White, C.B.; from the author.

Triple and Quadruple Expansion Engines and Boilers, by A. Ritchie Leask; from the author.

Breakdowns at Sea and how to repair them, by A. Ritchie Leask; from the author.

Mytton Hall—a catalogue of the principal Paintings &c. at the residence of John Hick, Esq.; from Mrs. Hick.

Engineering Education: Proceedings of Section E of the World's Engineering Congress, Chicago, 1893; from the Western Society of Engineers.

Theory and Construction of a rational Heat Motor, by Rudolf Diesel, translated by Bryan Donkin; from Mr. Bryan Donkin.

The Tower Bridge, by J. Wolfe Barry, C.B.; from the author.

Sanitary arrangement of Dwelling-houses, by A. J. Wallis Tayler; from the author.

Practical hints on the construction and working of Regenerator Furnaces, by Maurice Graham; from the author.

Inclined Gas-Retorts; from Mr. Maurice Graham.

The Steam-Engine and other Heat-Engines, by J. A. Ewing; from Cambridge University Press.

Boiler Construction, by W. D. Cruickshank; from the author.

Electric Transmission of Energy, fourth edition, by Gisbert Kapp; from Messrs. Whittaker and Co.

Electric-Light Installations, seventh edition, by Sir David Salomons, Bart.; from Messrs. Whittaker and Co.

Ports Maritimes de la France, Vol. VIII (two parts) and Atlas; from the Ministère des Travaux publics.

Atlas des Voies Navigables de la France—Canal de l'Oise à l'Aisne; from the Ministère des Travaux publics.

Tramways, their Construction and Working, second edition, by D. Kinnear Clark; from Messrs. Crosby Lockwood and Son.

Treatise on Hydrostatics, by A. G. Greenhill; from the author.

Report on Perennial Irrigation and Flood Protection for Egypt, by W. Willcocks; from Public Works Department, Egypt.

Practical Instructions for using the Steam-Engine Indicator; from Mr. George A. Mower.

The following official publications from the Government of New South Wales:—General Reports of Public Works Committee, 1893 and 1894; Annual Report of the Department of Public Works, 1892; Annual Report of the Department of Mines and Agriculture, 1893; Sixth Annual Report of the Metropolitan Board of Water Supply and Sewerage, 1892; Progress and Final Reports from the Select Committee on Working of Collieries; Report relating to the Proposed Railway from Narrabri to Moree; Wealth and Progress of New South Wales, 1893, by T. A. Coghlan.

Duty Tests of Pumping Engines and Reynolds Corliss Engines; from the Edward P. Allis Co.

The following from the Ordnance Office, Washington, United States:—Annual Report of the United States Chief of Ordnance, 1893; Notes on the Construction of Ordnance.

Presidential Address to the North of England Institute of Mining and Mechanical Engineers, 1893, by A. L. Steavenson; from the author.

Last Twenty Years in the Cleveland Mining District, by A. L. Steavenson; from the author.

Treatment of Manufactured Iron and Steel for Constructional Purposes, by W. F. How; from the author.

Contribution to the History of Fire-damp, by H. G. Graves; from the author.

Friction of Lubricated Bearings, by J. Hartley Wicksteed; from the author.

Measurement of Elongation in Test Samples, by J. Hartley Wicksteed; from the author.

Indian Currency, by Sir Guilford L. Molesworth, K.C.I.E.; from the author.

Comparison of Friction in Cotton-Mill Engines and Gearing with the actual work done, by Alfred Saxon; from the author.

Rede zum Geburtsfeste seiner Majestät des Kaisers und Königs Wilhelm II in der Aula der Königlichen Technischen Hochschule zu Berlin, 26 Januar 1894; from the Rector.

Classified List and Distribution Return of Establishment, Indian Public Works Department, to 31 Dec. 1893; from the Registrar.

Possibility of Mechanical Aeronautics without a Balloon, by D. K. Chernoff; from the author.

Waste of Heat, past, present, and future, in Smelting Ores of Iron, by Sir Lowthian Bell, Bart.; from the author.

Affairs of the Colony, a History concerning the Straits Settlements, by F. M. McLarty; from the author.

Descriptive Summary of the Ships and Engines constructed at Birkenhead Iron Works, 1829–1893; from Mr. William Laird.

Screws and Screw Making; from the Britannia Co.

The following from the author, Professor M. F. Gutermuth:—Dampfmaschinen auf der Welt-ausstellung in Chicago 1893; Kälte-verteilungs-anlagen in Amerika; Neuere Konstruktionen der amerikanischen Personen-aufzüge.

Report of Coal-Test Board on Victorian Black Coals; from Mr. William Conyers.

List of Chinese Lighthouses, Light Vessels, Buoys, and Beacons, 1894; from the Inspector-General of Chinese Customs.

Velocity of Combustion of an Explosive under variable pressure, by Lt. J. H. Glennon, U.S.N.; from the author.

Rapport sur les essais de 1893–94 dans le Laboratoire de Mécanique de l'École des Mines de Liége, by Professor V. Dwelshauvers-Dery; from the author.

Elektrische Eisenbahnen und Schiffe, Achte Gruppe.

Michigan Mining School, by M. E. Wadsworth.

Scandinavia as a source of Iron Ore Supply, by Jeremiah Head; from the author.

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Fifth Annual Report of the De Beers Consolidated Mines for year ending 30 June 1893; from Mr. Thomas Quentrall.

Revue de Mécanique Appliquée Pneumatique, by Edouard Sauvage; from the author.

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Memorial to Board of Trade re Domestic Boiler Explosions; from Mr. Lavington E. Fletcher.

Expériences et Études sur le Passage en Courbe du matériel roulant, by Edmond Roy; from Mr. Henry Chapman.

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Consumption of Steam and Water in Steam Engines, by W. I. Ellis; from the author.

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Report on Dry Cells of the Obach and the E. C. C. types, by Andrew Jamieson; from Messrs. Siemens Brothers and Co.

South African Association of Engineers and Architects, Second Annual Report 1894; from the Association.

Correspondence exchanged with the Legation of Portugal and the Legation of Brazil at Lisbon in regard to the Surrender of the Insurgent Refugees on board the Portuguese corvettes "Mindello" and "Affonso de Albuquerque"; from Messrs. Dulau and Co.

Message addressed to the National Congress by Marshal Floriano Peixota on occasion of the opening of the first ordinary session of the second legislature, Brazil; from Messrs. Dulau and Co.

Going to the Isle of Dogs, by Lesser Columbus; from Messrs. Bullivant and Co.

Ealing Electric Lighting; from Messrs. Bramwell and Harris.

Address to the Sanitary Inspectors' Association, 17th Aug. 1894, by W. A. Valon; from the author.

The Slide Rule, by C. N. Pickworth; from the author.

Annual Report of the Chief of the Bureau of Steam Engineering, United States Navy Department, 1894; from the Bureau.

Report of Test of Pumping-Engine No. 3, Louisville Water Co., with Combined Indicator Diagram; from Mr. E. D. Leavitt.

Chief Engineer's General Report upon the Initiation and Construction of Tunnel under the East River, New York; from Mr. C. M. Jacobs.

L'Or à Minas Geraes, Brazil, vol. I., by Paul Ferrand; from the author.

The Gas Manager abroad—Australia, by John Chamberlain; from the author.

Measurement Conversion Diagrams, by R. H. Smith; from the author.

Framed Photograph of Model of Southampton Docks and Harbour, with Key; from Mr. James P. Maginnis.

Register of the Institute of Chemistry of Great Britain and Ireland, 1894–95; from the Institute.

Nippon Yusen Kaisha, Handbook of information; from Mr. William Barrie.

Kitchen Boiler Explosions, by R. D. Munro; from the author.

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The Armour-Plate Question, 1894, by Capt. W. H. Jaques; from the author.

Transactions de Mons. G. Eiffel avec la liquidation de Panama; from Mons. G. Eiffel.

Latent Heat of Steam and Absolute Zero, by William Donaldson; from the author.

Profit and Loss of Gold-Mining, ancient and modern, by Nicol Brown; from the author.

Civil Engineering College, Sibpur, Calendar 1894; from the College.

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Report to the Governors of the City and Guilds of London Institute, April 1894; from the Institute.

Catalogue of Lead and Glass Works; from Messrs. T. and W. Farmiloe.

Catalogue of Steam-engines, Oil-engines, and Gas-engines; from Messrs. Robey and Co.

New York, the American Cosmopolis; from the Otis Elevator Co.

Spons' Engineers' and Contractors' Diary and Reference Book, 1895; from the publishers.

Catalogues of Steam Pumping Machinery; from the Blake and Knowles Steam Pump Works.

Gas Engineer's Pocket Almanack, 1894; from Messrs. William Sugg and Co.

Lockwood's Builder's and Contractor's price-book, 1894; from Messrs. Crosby Lockwood and Son.

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From the Patent Office.

The following Abridgments of Specifications of Patents for Inventions, 1877–83:—Classes 12, 14, 20, 22, 28, 56, 59, 60, 61, 83, and 136.

Without illustrations:—Acids, Alkalies, Oxides, and Salts, Divisions I–III; Electricity and Magnetism, Divisions I–VI; Manufacture of Iron and Steel; Metals and Alloys.

Illustrated Appendices:—Bleaching &c.; Fire-arms &c., Divisions I and II; Photography; Preparing and cutting Cork &c.; Sewing and Embroidering; Wearing-apparel, Divisions I–IV.

From the United States Geological Survey.

Twelfth and Thirteenth Annual Reports of the United States Geological Survey, 1890–91 and 1891–92, by J. W. Powell.

Mineral Resources of the United States, 1892 and 1893.

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The following three Monographs of the Survey :—

XIX. The Penokee Iron-bearing series of Michigan and Wisconsin, by Roland Duer Irving and Charles Richard van Hise.

XXI. Tertiary Rhynchophorus Coleoptera of the United States, by Samuel Hubbard Scudder.

XXII. A Manual of Topographic Methods, by Henry Gannett.

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Reports of the Academy of Science, France.
Engravings from the École des Ponts et Chaussées, Paris.
Annales des Ponts et Chaussées, Paris.
Proceedings of the French Institution of Civil Engineers.
Journal of the French Society for the Encouragement of National Industry.
Reports of the French Association for the Advancement of Science, 1892 and 1893.
Annales des Mines.
Annales du Conservatoire des Arts et Métiers.
Journal of the Marseilles Scientific and Industrial Society.
Proceedings of the Industrial Society of St. Quentin et de l'Aisne.
Proceedings of the Industrial Society of the North of France.
Proceedings of the Industrial Society of Rouen.
Proceedings of the Industrial Society of Mulhouse.
Annals of the Association of Engineers of Ghent.
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Reports of the Royal Institute of Engineers, Holland.
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Proceedings of the Engineers' and Architects' Society of Austria.
Proceedings of the Engineers' and Architects' Society of Prague.
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Journal of the Franklin Institute.
Transactions of the American Society of Civil Engineers.
Transactions of the American Society of Mechanical Engineers.
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School of Mines Quarterly, Columbia College, New York.
Reports of the Smithsonian Institution.

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Proceedings of the United States Naval Institute.
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Journal of the Association of Engineering Societies.
Journal of the United States Artillery.
Transactions of the Canadian Society of Civil Engineers.
Proceedings and Journal of the Asiatic Society of Bengal.
Proceedings of the Committee of Locomotive and Carriage Superintendents for India.
Proceedings of the Engineering Association of New South Wales.
Proceedings of the Institution of Civil Engineers.
Journal of the Iron and Steel Institute.
Transactions of the Society of Engineers.
Journal of the Institution of Electrical Engineers.
Transactions of the North of England Institute of Mining and Mechanical Engineers.
Proceedings of the South Wales Institute of Engineers.
Transactions of the Institution of Engineers and Shipbuilders in Scotland.
Transactions of the Chesterfield and Midland Counties Institution of Engineers.
Transactions of the Liverpool Engineering Society.
Transactions of the Midland Institute of Mining, Civil, and Mechanical Engineers.
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Transactions of the Mining Institute of Scotland.
Transactions of the North-East Coast Institution of Engineers and Shipbuilders.
Proceedings of the South Staffordshire Institute of Iron and Steel Works Managers.
Proceedings of the Royal Society of London.
Proceedings of the Royal Society of Edinburgh.
Proceedings of the Royal Institution of Great Britain.
Transactions and Professional Notes of the Surveyors' Institution.
Journal of the Royal United Service Institution.
Professional Papers of the Royal Engineers' Institute.
Journal of the Royal Agricultural Society of England.
Journal of the Royal Statistical Society.
Report of the British Association for the Advancement of Science.
Report of the Royal Cornwall Polytechnic Society.
Transactions of the Institution of Naval Architects.
Journal of the Royal Institute of British Architects.
Transactions of the Incorporated Gas Institute.
Proceedings of the Physical Society of London.
Proceedings of the Literary and Philosophical Society of Manchester.
Transactions of the Manchester Geological Society.

Journal of the Royal Scottish Society of Arts.
Proceedings of the Philosophical Society of Glasgow.
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Transactions and Proceedings of the Royal Dublin Society.
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Journal of the Society of Arts.
Journal of the Society of Chemical Industry.
Journal of the Society of Architects.
Transactions of the Manchester Association of Engineers.
Transactions of the Junior Engineering Society.
Reports of the Manchester Steam Users' Association; from Mr. Lavington E. Fletcher.
Report of the National Boiler and General Insurance Company; from Mr. Edward G. Hiller.
Report of the Engine, Boiler, and Employers' Liability Insurance Company; from Mr. Michael Longridge.
Report to the Council of the Neapolitan Steam Boiler Association, by Francesco Sinigaglia; from the Association.
Report of the London Association of Foremen Engineers and Draughtsmen.
Twenty-third Annual Report of the Bradford Free Public Libraries.
Forty-first Annual Report of the Liverpool Free Public Library.
Forty-second Annual Report of the Manchester Public Free Libraries.
Twelfth Annual Report of the Newcastle-on-Tyne Public Libraries.
Catalogue of Additions to the Radcliffe Library, Oxford, during 1893.

The following Periodicals from the respective Editors:—

The American Engineer and Railroad Journal.
Arms and Explosives.
The Builder.
Camera Club Journal.
Cassier's Magazine.
Der Civil-Ingenieur.
The Colliery Guardian.
The Contract Journal.
The Electrical Engineer (from Mr. John T. Ewen).
Electrical Plant.
The Electrical Review.
The Engineer.
Engineering.
The Engineering and Mining Journal.
The Engineering Review.
The Fireman.
Giornale del Genio Civile.
Glaser's Annalen.
Hardware Trade Journal.
The Indian Engineer.
L'Industrie.
Industries and Iron.
Ingeniero y Ferretero Español y Sud Americano.

The Iron and Coal Trades Review.
Iron Trade Circular, Ryland's.
The Ironmonger.
Ironmongery.
Lightning.
The Machinery Market.
The Marine Engineer.
The Mechanical World.
The Mining Journal.
Phillips' Monthly Machinery Register.
The Plumber and Decorator.
The Practical Engineer.
The Railway Engineer.
Railway Engineering and Mechanics.
The Railway Review.
Revue générale des Chemins de fer.
Revue industrielle.
Revue universelle des Mines.
The Shipping World.
Stahl und Eisen.
The Steamship.
The Textile Recorder.
Transport.

The PRESIDENT, in moving the adoption of the Report of the Council, alluded to the honours therein mentioned as having been conferred during last year upon Members of this Institution; and he was sure that, as a matter of personal feeling and esteem, the Members would all join heartily in the congratulations which the Council had offered to their colleague, Dr. White, on his having received at the beginning of this year the honour of being made a Knight Commander of the Bath, in recognition of the important services he was rendering to the nation in the distinguished and responsible position he occupied.

In the matter of Research, the experiments which had been made in France upon the use of Ropes and Belts for the Transmission of Power would probably afford in the near future a good deal of interesting material for discussion. Professor Capper, having been present at the experiments along with the other engineers who formed the Committee appointed to look after them, would in due course give the Institution a paper embodying the results arrived at. These he believed were the first practical experiments on the subject which had really been made on any extensive scale.

Another matter that he wished to mention, because it was one in which he had himself a great personal interest, was the presentation

to the Institutions of Mechanical and Electrical Engineers of the fund collected by the friends of the late Mr. Willans, for the purpose of perpetuating in some respects his memory. Although naturally to those who were his friends nothing of the kind was necessary, yet, apart from all personal considerations, his work on the scientific side of engineering was well worthy of being commemorated, and he wished this could have been accomplished on a larger scale. The final result of what had been done was that the fund raised had been placed in the hands jointly of the Institutions of Mechanical and Electrical Engineers, for the purpose of awarding triennially a premium for a paper on such a general subject as the utilization or transformation of energy, treated especially from the point of view of efficiency or economy. It was the desire of those who had moved in this matter that the subject should be made as broad as possible, so as to embrace a large area of the work done by both Institutions. A joint Committee of the two Institutions had drawn lots as to which should have the honour of first awarding the premium; and the lot had fallen to the Institution of Electrical Engineers, by whom therefore the first award would be made three years hence. The Institution of Mechanical Engineers would afterwards make their presentation in turn. It was not of course for any intrinsic value of the premium itself that he now drew attention to it, but because he believed that any of the Members would consider it an honour to have their name and work associated with the name of Peter William Willans.

Among the donations to the Library during the past year were the curious Japanese Cast-Iron Kettle and pair of Japanese Magic Mirrors now placed upon the table, which had been sent by Mr. Thomas Bunt, the Superintendent Engineer of Kiangnan Arsenal at Shanghai. Having been over in Japan lately, he had been struck with the workmanship on some of the cast-iron kettles used there; of these he had sent the specimen here shown, thinking it might interest the Members to see what could be done in the way of moulding in the east. The making of the magic mirrors Mr. Bunt believed was a lost art; and it was rather difficult now to get those which would give a good reflection.

(The President.)

He now moved that the Annual Report of the Council with the statement of accounts be adopted.

Mr. R. Price-Williams was sure it must be highly gratifying to the Members to see that the financial position of the Institution was so satisfactory. In view of the large amount of the investments, he asked whether the large amount of capital in hand could not be better utilized than by being merely invested in securities giving but little more interest than consols. The present hospitable reception accorded by the Institution of Civil Engineers, now engaged in erecting a new building for themselves, had suggested forcibly the enquiry whether the time had not come when the Institution of Mechanical Engineers should also have a house of their own. While they were of course most grateful to the Institution of Civil Engineers for their ever obliging hospitality, he really thought that, having regard to their own position and resources, it was desirable that at an Annual General Meeting like the present the subject should be ventilated. The membership and the prestige of the Institution he was confident would be appreciably enhanced if the course he suggested were adopted; and he had himself long entertained the idea that an Institution of this standing ought not to be in the position of having to accept the assistance, however generously offered, of a kindred Institution. Having during the last few years been absent a good deal in other lands, he had unfortunately not been able to attend the meetings as much as he should have liked to do; but he had taken a deep interest in the Institution ever since he became a Member thirty-six years ago, and anything he could do to promote its interests he would do most gladly.

The President assured Mr. Price-Williams that the Council were glad to hear what he had said, for they had themselves so far thought a case had been made out for spending their somewhat large capital in housing the Institution, that a committee of the Council had now been appointed for the purpose of making a preliminary enquiry into the subject, and reporting upon it.

The motion for the adoption of the Annual Report of the Council with the statement of accounts was then put to the Meeting, and agreed to.

The PRESIDENT reminded the Members that at the present meeting the appointment of a professional Accountant to audit the accounts of the current year had to be made, and his remuneration fixed. The present auditor, Mr. Robert A. McLean, chartered accountant, offered himself for re-election at the same remuneration as last year.

Mr. SAMUEL DIXON believed the present auditor had done the work during the last seventeen years with thorough efficiency, and consequently needed no recommendation for re-election on this occasion. He had therefore much pleasure in moving the formal resolution, that Mr. Robert A. McLean, chartered accountant, 1 Queen Victoria Street, London, be re-appointed to audit the accounts of the Institution for the current year at the same remuneration as at present, namely Twenty-five Guineas.

Mr. SAMUEL CHATWOOD seconded the motion.

Mr. J. MACFARLANE GRAY had no fault whatever to find with the way in which the accounts had hitherto been audited; but he thought prudence should lead to alternating the auditor. Without wishing now to propose any amendment to the resolution which had been moved, he would suggest that before the next annual general meeting the Council should consider the propriety of another auditor being occasionally appointed.

The PRESIDENT had no doubt the Council would take the suggestion into their consideration.

The resolution was then put and carried.

The PRESIDENT announced that the Ballot Lists for the election of Officers for the present year had been opened by a committee of the Council, and that the following were found to be elected:—

PRESIDENT.

ALEXANDER B. W. KENNEDY, LL.D., F.R.S., . London.

VICE-PRESIDENTS.

SAMUEL W. JOHNSON, ... Derby.
J. HARTLEY WICKSTEED, ... Leeds.

MEMBERS OF COUNCIL.

JOHN A. F. ASPINALL, ... Horwich.
WILLIAM DEAN, ... Swindon.
BENJAMIN A. DOBSON, ... Bolton.
BRYAN DONKIN, ... London.
FRANCIS C. MARSHALL, ... Newcastle-on-Tyne.
HENRY D. MARSHALL, ... Gainsborough.

For supplying the vacancy amongst the Members of Council, consequent upon the election of Vice-Presidents, the Council had appointed Mr. A. TANNETT WALKER as a Member of Council for the present year, his name standing next highest in the voting for the election at this Meeting.

The Council for the present year will therefore be as follows:—

PRESIDENT.

ALEXANDER B. W. KENNEDY, LL.D., F.R.S., . London.

PAST-PRESIDENTS.

DR. WILLIAM ANDERSON, F.R.S., . . . London.
THE RT. HON. LORD ARMSTRONG, C.B., D.C.L.,
LL.D., F.R.S., ... Newcastle-on-Tyne.
SIR LOWTHIAN BELL, BART., F.R.S., . . . Northallerton.
SIR FREDERICK J. BRAMWELL, BART., D.C.L.,
LL.D., F.R.S., ... London.
SIR EDWARD H. CARBUTT, BART., . . . London.
CHARLES COCHRANE, ... Stourbridge.

Jeremiah Head, ...	London.
John Ramsbottom, ...	Alderley Edge.
John Robinson, ...	Leek.
Percy G. B. Westmacott, ...	Newcastle-on-Tyne.

VICE-PRESIDENTS.

Sir Douglas Galton, K.C.B., D.C.L., F.R.S., .	London.
Samuel W. Johnson, ...	Derby.
Edward P. Martin, ...	Dowlais.
Sir James Ramsden, ...	Barrow-in-Furness.
E. Windsor Richards, ...	Low Moor.
J. Hartley Wicksteed, ...	Leeds.

MEMBERS OF COUNCIL.

John A. F. Aspinall, ...	Horwich.
William Dean, ...	Swindon.
Benjamin A. Dobson, ...	Bolton.
Bryan Donkin, ...	London.
Dr. John Hopkinson, F.R.S., . . .	London.
Arthur Keen, ...	Birmingham.
William Laird, ...	Birkenhead.
John G. Mair-Rumley, ...	London.
Francis C. Marshall, ...	Newcastle-on-Tyne.
Henry D. Marshall, ...	Gainsborough.
William H. Maw, ...	London.
James Platt, ...	Gloucester.
T. Hurry Riches, ...	Cardiff.
A. Tannett Walker, ...	Leeds.
Sir William H. White, K.C.B., LL.D., F.R.S.,	London.

The President announced that the Summer Meeting of the Institution in the present year would be held in Glasgow, under the auspices of the Honourable the Lord Provost, James Bell, Esq., and the Magistrates and Town Council of that city.

The PRESIDENT said it was no doubt in the knowledge of the Members generally that a great piece of work, which had been carried out by their Honorary Life Member, Lord Rayleigh, in conjunction with Professor Ramsay, had today attained its virtual consummation by being formally presented to the Royal Society:—namely the discovery, by these two pioneers in physical research, of a new constituent of the atmosphere. This discovery had been well described as not unworthy to be placed beside Priestley's original discovery of oxygen, or Adams' discovery of the planet Neptune: which he imagined meant that it was perhaps the greatest discovery that had been made within the recollection of most of those here present. That one of their honorary life members should have taken a leading part in this discovery was a matter on which they might congratulate both him and themselves; and they might do it all the more warmly, seeing that the discovery was not a mere chance affair, but was arrived at by a series of deductions starting from the detection of a certain uniform difference of something like half of one per cent. between the density of nitrogen as taken from the atmosphere and as obtained by chemical reaction. This difference was so small that most persons would have taken it for a mere error of observation. But Lord Rayleigh had not done so: he believed in his own observations, and together with Professor Ramsay he saw what they must mean if they were right. Through good report and ill report—and notwithstanding what he could not help calling unworthy treatment on the part of some persons and some papers that ought to have known better—he had worked steadily on, until he had been able today to present the discovery to the Royal Society as absolutely undeniable. It was therefore with the greatest pleasure that he now begged to move that "The Members of the Institution of Mechanical Engineers, at their Annual General Meeting, desire to congratulate the Lord Rayleigh, Secretary of the Royal Society and Honorary Life Member of the Institution, and his colleague, Professor William Ramsay, F.R.S., upon the investigation carried out by them, which has resulted in the discovery of a new element, a constituent of the atmosphere, and which has today been formally described by them to the Royal Society."

Mr. JEREMIAH HEAD, Past-President, desired to second the motion proposed by the President. While the Members of this Institution were all in the main concerned with applied science, he was quite sure that they appreciated none the less the labours of those who in the main were devoted to pure science, and that they would carry with enthusiasm the resolution now moved. Lord Rayleigh and his colleague, Professor Ramsay, he apprehended would appreciate the compliment thus paid to them by the Institution.

The PRESIDENT in putting the motion added that at the meeting of the Royal Society it had been pointed out by Professor Roberts-Austen that, while the discovery not only arose from so minute an origin but also seemed to be one which was so much outside their ken, yet something like a thousand cubic feet of the new element "argon," unknown till the present time, went through a Bessemer converter at every blow of ten tons of steel. Thus it was not a substance that was dealt with only in small quantities; possibly it might indeed, for anything yet known of it, be the secret of the influence which formerly nitrogen had been supposed to exert upon steel; but in view of its extreme inertness this was perhaps unlikely.

The motion was unanimously adopted.

The following Paper was then read and partly discussed:—

"The Determination of the Dryness of Steam;" by Professor W. CAWTHORNE UNWIN, F.R.S., of London.

Shortly before Ten o'clock the Meeting was adjourned to the following evening. The attendance was 100 Members and 78 Visitors.

The ADJOURNED MEETING was held at the Institution of Civil Engineers, London, on Friday, 1st February 1895, at Half-past Seven o'clock p.m.; Professor ALEXANDER B. W. KENNEDY, LL.D., F.R.S., President, in the chair.

The Discussion upon Professor Unwin's Paper on the Determination of the Dryness of Steam was resumed and concluded; and the following Paper was read and partly discussed:—

"Governing of Steam Engines by Throttling and by Variable Expansion;" by Capt. H. Riall Sankey, of Thames Ditton.

On the motion of the President a vote of thanks was unanimously passed to the Institution of Civil Engineers for their kindness in granting the use of their rooms for the Meeting of this Institution.

The Meeting then terminated at a Quarter to Ten o'clock, the Discussion upon Capt. Sankey's Paper being adjourned to the Spring Meeting of the Institution. The attendance was 80 Members and 110 Visitors.

THE DETERMINATION OF THE DRYNESS OF STEAM.

By Professor W. CAWTHORNE UNWIN, F.R.S.

Every engineer who has to do with the manufacture or use of steam machinery will know that a large amount of experimental research has been carried out during the last ten or fifteen years, on the action of Steam in the engine, and on the causes of waste of energy in the production and application of steam power. The testing of boilers and engines with a view to determine their comparative economy has come to be a matter of considerable practical and commercial importance. Not only are boilers and engines contracted for under stringent guarantees as to the amount of coal and steam they will use, but the results of trials are published in a kind of open competition; and there is a tendency to record-breaking in engine tests, as well as in trials of a more sporting kind. For commercial reasons therefore, as well as for scientific reasons, it is important that the observations taken in an engine or boiler trial should be complete and accurate, and that the instruments used should be of the most satisfactory and trustworthy character.

In such trials there has been one important observation which has hitherto been difficult, and which has been made by methods of doubtful trustworthiness. The Dryness of the Steam is a quantity which, in either a boiler trial or an engine trial, it is important to determine. If a boiler produces wet steam, it is credited with greater evaporative efficiency than it deserves, if the amount of unevaporated water is not ascertained. If an engine is supplied with wet steam, its thermal efficiency will be diminished, and it will be undeservedly discredited unless the quality of the steam is known. It has long been understood that it is desirable in both boiler trials and engine trials to determine the quality of the

steam; but the methods for measuring the amount of moisture in steam were troublesome to carry out, and when used they gave results which were more or less discordant and doubtful. It occurred to the author to suggest at the Edinburgh meeting of the British Association that a committee should be constituted to examine the various methods of determining the dryness of steam. A committee was formed with Sir Frederick Bramwell, Bart., as Chairman; and a report was presented at last year's Oxford meeting. The present paper contains some account of the methods described in that report, and of the conclusions arrived at in trials of different methods.

The earliest attempts to determine the amount of moisture in steam, of which records have been found, were made during some boiler trials carried out by a committee of the Société Industrielle of Mulhouse in 1859. This committee tried three different methods —a method of separation, a condensing method suggested by Hirn, and a chemical method. In these early trials the condensing method only, in which the total heat of a sample of the steam was measured, appeared to give satisfactory results. But although the committee did not place full reliance on any of their methods, these have all been used by various experimenters down to the present time.

Origin of the Water suspended or entrained in Steam.—The water found in a sample of steam may have come there in one of three ways.

(1) Water projected into the steam space during ebullition may be carried forward in the current of steam. The extent to which wetness is thus produced depends on the activity of the ebullition, the area of the water surface, the volume of the steam space, the position of the steam valve, the density of the steam, and, probably more than anything else, on the quality of the water and its liability to produce *foam*. Mr. Thornycroft has made some instructive observations on the priming produced when water foams. He constructed a boiler with glass ends, through which the process of boiling could be seen. As the result of observations* on this boiler

* Circulation in the Thornycroft Water-Tube Boiler. Transactions of the Institution of Naval Architects, 1894, vol. xxxv, page 290.

he states that waters which cause priming produce foam on boiling. Water which is very bad produces bubbles so durable as to remain a considerable time without breaking; and by them the steam space of a boiler may be entirely filled. So soon as this takes place, instead of simply steam leaving the boiler, the discharge consists of foam, which becomes broken up in its rapid passage through the steam pipe. With pure water, steam retains no film of liquid long enough to be seen.

(2) Water may be produced in steam from the expansions to which it is subjected. Fluctuations of pressure arise from the intermittent demand for steam, and from the steam passing from places of higher to places of lower pressure. But it is difficult to believe that any great amount of wetness arises in this way in ordinary cases.

(3) The steam in the steam space of the boiler, and when flowing through the steam pipes, loses heat by radiation from the boiler roof and the surfaces of the pipes; and there is consequently a condensation of part of the steam. Probably in some cases considerable wetness is produced in this way. In any individual steam plant, the absolute amount of moisture produced by radiation in a given time will be constant, and independent of the demand for steam. The wetness of the steam therefore, so far as it is due to this cause, will increase as the demand for steam diminishes.

Methods of Determining the Wetness of Steam.

1. *Weighing method.*—The density of saturated or very approximately saturated steam, of the quality of that in Regnault's total-heat experiments, can be directly determined on thermodynamic principles; and the result is confirmed by Fairbairn's experiments. Hence if a known volume of steam is weighed, any excess of weight above that of a corresponding volume of dry saturated steam must be due to the water present. A method of direct weighing has been proposed by Guzzi (Revue Industrielle, 1878, page 102), and by Knight (Journal of the Franklin Institute, 1877, page 358). The method is obviously one of excessive difficulty.

2. *Separating method.*—It is common to separate in a steam separator a great part of the water entrained in steam. In ordinary steam separators however the volume passing through is very large compared with the capacity of the separator, and the action is no doubt imperfect. In a separator dealing with only a small fraction of the steam, more perfect separation might be expected. Mr. G. A. Barrus, using a small separator in connection with a superheating calorimeter, noticed that nearly all the entrained water was trapped, and that the steam passing into the superheating vessel was nearly dry. More recently Professor Carpenter of Cornell University has introduced a form of separating calorimeter, shown in Fig. 1, Plate 1, which appears to give highly consistent and trustworthy results, and can be used with great facility. It consists of a vessel A, about 7 inches high by 3 inches diameter, consisting of an inner chamber and a jacket. The steam from the steam pipe S passes first into the inner chamber, where the moisture is separated, and then into the outer chamber. The separating chamber is therefore perfectly protected from radiation. As the water accumulates in the inner chamber, its level is shown by a gauge glass G, and the amount in hundredths of a pound can be read off on a scale. A very small orifice at the bottom of the outer chamber regulates the amount of steam discharged. The escaping steam passes through a flexible tube to a simple form of condenser C. The increase of weight in any given time in the condenser is noted, and the amount accumulated in the same time in the separator. If x is the dryness fraction of the steam, w the weight of water caught in the separator, and W the weight of steam condensed, then $x = W \div (W + w)$. There is a gauge glass and scale on the condenser, graduated to read pounds and tenths at a temperature of 110° F. But as the variation of volume in the condenser with temperature affects the readings considerably, it is best to place the condenser on a platform weighing-machine. Professor Carpenter states that the dryness of the steam after passing the separator was tested in the laboratories at Sibley College by several observers, and with steam carrying from $\frac{1}{4}$ per cent. to 60 per cent. of moisture. In every case the separation of the water from the steam was complete and perfect.

Other tests have been made with moderately dry steam, using the throttling and separating calorimeters simultaneously; and the results were practically identical. The instrument is very simple to use, and requires no pressure-gauge or thermometers.

3. *Condensing method.*—Suppose a known weight of the steam to be condensed, and its total heat to be determined by the rise of temperature of the condensing water. By comparing the total heat per pound of a sample of steam with that of a pound of dry saturated steam according to Regnault's tables, the amount of moisture in the steam can be determined. This method was first suggested by Hirn; and the apparatus which he designed for use in the Mulhouse Boiler Trials of 1859 is perhaps the most convenient form of apparatus for determinations by this method. As shown in Fig. 2, Plate 2, it consists of an iron vessel C, about a foot in diameter, furnished with a loose cover; this forms the condenser. A small pipe and cock in the steam pipe deliver steam through a small orifice near the steam pipe into the pipe S, through which it passes into the condensing water. An agitator G and a sensitive thermometer I are provided in the condenser. For weighing the amount of steam condensed, the whole condenser is suspended from a hydrostat H, which permits extremely accurate determination of any change of weight. The hydrostat is balanced by weights till the pointer P is at a fixed mark before and after condensing the steam.

Let x be the dryness fraction of the steam, w the increase of weight of the condenser during the test. Then the condenser has received $x\,w$ lb. of dry steam, and $(1-x)\,w$ lb. of water at the steam temperature. Let W be the weight of water initially in the condenser, plus the equivalent of the condenser itself reckoned as water. Let t be the temperature of the steam, and i and f the initial and final temperatures of the condenser water. Then, using the ordinary approximate equations,

$$x\,w\,(1116-0\cdot71\,t)+w\,(t-f)=W\,(f-i);$$

$$\text{whence } x=\frac{W\,(f-i)-w\,(t-f)}{w\,(1116-0\cdot71\,t)}$$

To arrive at satisfactory results the temperatures must be read to one-tenth of a degree Fahr. at least, and the weight of steam condensed must be very accurately determined. It is desirable that the initial temperature i of the condenser water should be about as much below the temperature of the place where the test is made as the final temperature f is above it. A correction for radiation during the time that the agitator is used before the final temperature f is read can be made thus. Suppose the agitator is used for two minutes, and the temperature is then f_1; and that two minutes later a temperature f_2 is observed. Then the true value of the final temperature f at the moment when condensing ceased is $f = 2 f_1 - f_2$. In the Mulhouse tests the initial and final temperatures were about 60° and 110° F.; and the steam generally showed from $2\frac{1}{2}$ to 5 per cent. of moisture, but in particular cases as much as 12 to 16 per cent. of moisture was observed.

The condensing or total-heat method of ascertaining the dryness of steam has been used by many observers during the last thirty years. An apparatus for making this test is known in America as the Barrel Calorimeter. An ordinary oil barrel is used, fitted with an outlet valve. The barrel is filled with cold water, and steam is led into it by a pipe and condensed. The barrel is placed on a weighing machine, and the weight and temperature before and after condensing are noted. The proceeding is a rough one, and has given anomalous results in practice. Mr. Willans used this method in his trials of a non-condensing steam engine.* He sought to evade the known difficulties of the method by carrying it out on a very large scale. A condensing tank, weighing with water about three tons, was placed on a platform weighing-machine. This was balanced by the sliding weight of the weighing-machine. Then a standard hundred-weight was placed on the platform, and the machine lever again put in balance. The hundred-weight was then removed, the temperature noted, and steam condensed till the added weight of condensed steam just lifted the lever, making an electric signal. Then the water was stirred, and the temperature again noted. The

* Proceedings of the Institution of Civil Engineers, 1888, vol. xciii, page 128.

thermometers were very sensitive, and were accurately compared with standard thermometers. A small correction was made for radiation. The value of the dryness fraction found on different days was 0·9996, 0·9638, 0·9949, 0·9646, 0·9976, 0·9893, 1·0072, 1·0048, 0·9987. The mean of all was 0·9911, showing an average of about 1 per cent. of moisture in the steam. Probably this test was never more carefully carried out; but the results are not so accordant as could be wished. Two of the results indicate superheating, which under the circumstances was probably impossible.

The condensing or total-heat method is strictly accurate in principle, but it is difficult to carry out satisfactorily. It is not easy to make the proper allowances or corrections for the heat absorbed by the condensing vessel itself, and for radiation and loss by evaporation from the condenser. The thermometers must be very sensitive; and very sensitive thermometers are difficult to use.

4. *Continuous Condensing methods.*—The difficulties of the ordinary condensing method were so obvious that Mr. Barrus, Mr. Hoadley, and other observers were led to propose methods of continuous condensation. Steam and cold water being both supplied at a constant rate, the condenser acquires a steady temperature, which can be very accurately observed. The steam may be condensed either in the condensing water or in a surface condenser. In Fig. 3, Plate 3, is shown a continuous injection-condenser. Steam passes from the steam pipe S to a small injector I. The condensing water is drawn from the tank A, and the mixed water and condensed steam are discharged into the tank B. The two tanks are placed on platform weighing-machines. Thermometers TT give the temperatures of the condensing water and of the mixture of condensed steam and condensing water. The difference of the total weight in the two tanks after any interval of time is the steam condensed in that time. In Fig. 4, Plate 4, is shown a continuous surface-condenser, consisting merely of a small pipe A in a vessel, through which flows a steady stream of condensing water. As the condensing surface is constant, the rate of condensation is constant, and the rise of temperature of

the condensing water is constant. The condensed steam is drawn off steadily from the condenser for weighing, and simultaneously a series of readings are taken of the water entering and leaving the condenser. The continuous condensing method seems likely to be more accurate than the ordinary method; but it involves more elaborate arrangements, and it does not seem to have been much used in practical trials.

5. *Superheating method.*—About 1890 Mr. G. H. Barrus* devised a calorimeter, in which the steam to be tested passed through an inner chamber jacketed by superheated steam. The sample of steam to be tested was thus dried and superheated at the expense of heat borrowed from the jacket. To avoid measuring the steam, an attempt was made to secure that equal weights of steam passed through the inner chamber and through the jacket. In that case the wetness of the steam can be calculated from observation of the temperatures only. The method is accurate in principle, but appears to be difficult to carry out satisfactorily.

6. *Wire-drawing method.*—A method in which the steam to be tested is dried and slightly superheated by wire-drawing was proposed by Professor Peabody. Mr. Barrus and others have devised modified forms of the apparatus. In Fig. 5, Plate 4, is shown Mr. Barrus's arrangement. The steam passes from a chamber A to a chamber B through a very small aperture, about 1-16th inch in diameter. The full steam pressure is in A, and the pressure in B differs little from atmospheric pressure. Thermometers TT give the temperatures in the chambers, which are protected from radiation by a thick coating of asbestos and felt. The steam is allowed to flow through the apparatus for twenty minutes or more, when the temperatures become nearly steady. Let t_1 t_2 be the temperatures of the steam before and after wire-drawing, t_3 the temperature of saturated steam corresponding with the pressure in the second chamber B. Then the steam in B

* "Boiler Tests," by Barrus, Boston, 1891, page 18. "Experimental Engineering," by Carpenter, page 386.

has been superheated $t_2 - t_3$ degrees by wire-drawing. Let h_1 L_1 be the liquid heat and latent heat of steam at t_1, and h_3 L_3 corresponding quantities for steam at t_3. Taking as usual the specific heat of water as unity, and that of steam as 0·48, the dryness fraction $x = \frac{t_3 - t_1 + L_3 + 0 \cdot 48 \ (t_2 - t_3)}{L_1}$. No weighing is required, and temperatures only have to be observed. The observations can be continued as long as desired, so as to obtain a mean value for the dryness fraction x from a considerable quantity of steam. If the steam is very wet, the temperature in B falls to about 212°, showing that wire-drawing to atmospheric pressure is insufficient to dry the steam. Practically the instrument cannot be used if the wetness exceeds the values given in the following table, the pressures being in lbs. per square inch and the atmospheric pressure being assumed at 14·7 lbs.

Initial Pressure (absolute).	Initial Pressure (gauge).	Initial Temperature. Fahr.	Initial Wetness. Per cent.
29·9	15·2	250°	0·80
67·2	52·5	300°	2·44
135·1	120·4	350°	4·21
247·7	233·0	400°	6·13

Two conditions are necessary for accuracy in using this method. The second chamber B must be large enough for the eddies to die out before the steam leaves the chamber. Radiation must be so far prevented that the steam in the chamber is not sensibly cooled. As a large quantity of heat is passing through the chamber, it appears that, when reasonable precautions in clothing the apparatus are taken, the loss by radiation is so small a fraction that it produces no important effect.

7. *Combined Separating and Wire-drawing methods.*—To extend the usefulness of the wire-drawing method, Mr. Barrus added a separator C, Fig. 5, Plate 4. The steam in passing through the separator leaves most of its moisture there; and the remainder is measured in the wire-drawing part of the instrument. When thus arranged the use of the instrument is much more troublesome, as

the amount of steam passing through in a given time must be observed, and the amount of moisture collected in the same time must be weighed. A condenser must therefore be used, at least occasionally, in order to determine the discharge per minute by the apparatus at different pressures. A formula can be found, connecting the discharge per minute with the fall of pressure in the chambers A and B; but it is not clear that the calculation of the steam used from the formula is quite accurate enough for the purpose; and using the condenser in every test is troublesome.

In Fig. 6, Plate 5, is shown a modification of Mr. Barrus's apparatus, which is manufactured by the Globe Engineering Company. A gauge glass is added to the separator, for facilitating the observation of the quantity of steam trapped. At the bottom of the separator is a cock, by which the water can be drawn off, or the level in the gauge glass regulated. The Globe calorimeter is well arranged and neatly made; but a condenser should be supplied with it, and be capable of easy attachment to the discharge pipe. The separating and wire-drawing parts in this instrument cannot be used independently.

8. *Second Superheating method.*—Mr. W. R. Cummins has suggested another method. A vessel is filled with the steam to be tested, and then heated by a jacket. As it is heated, the rise of pressure in the inner vessel is observed, the volume being constant. So long as the steam is moist, the pressure will rise with the temperature according to the law for saturated steam. The moment all the moisture is evaporated, the rate of rise of pressure with temperature will become much slower. Both inner chamber and jacket are first blown through with steam from the steam pipe. Next both are closed, and heat is supplied to the jacket. During this process the temperature and pressure in the inner chamber are observed at short intervals of time; and the temperature t_2 is found, at which, from the change in the rate of increase of pressure, the steam has just become dry. Let t_1 be the initial temperature of the steam, and v_1 v_2 the specific volumes of saturated steam corresponding to the temperatures t_1 t_2. Then the initial dryness fraction x of the

steam is $x = v_2 \div v_1$. The method is correct in principle, and there does not seem to be any insuperable difficulty in using it; but it does not appear that it has been tried.*

9. *Chemical methods.*—Let a soluble salt be added to the boiler water, so as to form a solution of known strength at any given time; and let the boiler be afterwards fed with pure water. If the steam leaving the boiler is dry saturated steam, the boiler solution should remain of constant strength. But if there is priming, part of the boiler water will be removed with its percentage of salt, and the solution in the boiler will diminish in strength. This method has been often used from the date of the Mulhouse experiments in 1859 to the present time. There are three variations of the mode of procedure.

(*a*) The decrease of saltness of the boiler water in a given time can be determined by taking samples from a gauge cock and analysing them. The sample should be drawn off through a worm cooled so that the water is below 212° at the point of discharge; otherwise there will be a loss by evaporation, which will alter the saltness of the sample. Care should be taken that the level in the boiler is the same when the initial and final samples are taken.

(*b*) A sample of the steam may be condensed in a small surface-condenser, and the amount of salt present in the condensed steam can be determined. Numerous samples should be taken during a trial, so as to obtain an average value of the dryness fraction of the steam.

(*c*) Mr. Escher of Zurich † has suggested another mode. The boiler is fed with water containing a constant percentage of soluble salt. During working the solution in the boiler steadily concentrates. If the boiler primes, the concentration will reach a fixed limit when the amount of salt in the concentrated solution removed by the priming water is as great as the amount of salt introduced in the same time by the weaker feed-water. If the limit of concentration

* Transactions of the North-East Coast Institution of Engineers and Shipbuilders, 1893, vol. ix, page 233.

† Der Civilingenieur, 1879, page 51.

and the quantity of feed supplied are known, the dryness of the steam can be exactly determined, at least so far as the moisture in it is due directly to priming. Mr. Escher has shown how the dryness can be approximately determined from the concentration in a given time, when the limit is not reached. This method appears to be accurate in principle, as a means of determining the amount of mechanical priming; but no record has been found of its having been tried.

The author has examined the results obtained by the salt methods (*a*) and (*b*) in a number of boiler trials; and he believes that these justify the following general conclusions. (1) According to the salt test there is usually less than one-fifth of one per cent. of moisture in the steam produced; whereas in tests of the same steam by other methods a considerably greater amount of moisture is indicated. No doubt this arises partly, perhaps principally, from the fact that the salt test can show only that part of the moisture in the steam which is due to mechanical priming. It may be inferred that in ordinary cases a sensible proportion of the moisture in steam is due, not to mechanical priming, but to condensation in consequence of radiation occurring after the steam is formed. (2) The results obtained by salt tests during any one boiler trial are not closely accordant, and results by method (*a*) do not well agree with results by method (*b*). This throws some doubt on the accuracy of the methods. (3) In cases where there was obviously a good deal of mechanical priming, the wetness shown by salt tests in successive samples of the steam is extremely variable. In a trial by Dr. Bunte, for instance, tests by method (*b*) showed from no wetness up to 13 per cent. of moisture, the mean being $3\frac{1}{4}$ per cent. At the same time method (*a*) gave 1·7 per cent. of moisture. It is obvious that in method (*a*) there must be great difficulty in securing a uniform distribution of salt in the boiler; and if this is not obtained, it is impossible to get average samples of the boiler water. The fact that the feed is supplied at one definite place tends to prevent a uniform distribution of saltness. In method (*b*) it would seem that the amount of steam which can conveniently be condensed is not large enough to be an average sample of the steam. A subordinate question is this. Some engineers have thought that the salt method was most suitable for

boiler trials, because it gives directly the mechanical priming; while other methods were more suitable for engine trials, where a knowledge of the absolute dryness of the steam was required. It seems doubtful whether the salt test does give the mechanical priming accurately; but also the view seems to be founded on a misapprehension. In determining the evaporative efficiency of a boiler, it is necessary to know how much of the feed leaves the boiler as steam, and how much as water. The total heat utilized depends on the dryness of the steam leaving the boiler. It does not matter how moisture originates in the steam, provided it is there. Moisture produced by radiation from the boiler roof is as much a deduction from the efficiency of the boiler as moisture projected into the steam mechanically. It is important in a boiler trial that the steam tested should be taken very near the boiler, and not from a steam pipe in which heat may have been lost by radiation. On the other hand in an engine trial it is desirable that the sample of steam should be taken very near the engine.

Practical Conclusions as to the most convenient and accurate methods.

The chemical methods the author thinks may be put aside as both inconvenient and untrustworthy, except perhaps in the single case of a boiler subject to marked priming action. In that case the use of the salt test according to method (*a*) might be useful, because virtually it integrates the loss of boiler water by mechanical priming over any desired length of trial, and because, where the wetness of the steam is large, the defects of the method, especially the difficulty of securing average samples of the boiler water, are proportionately less serious.

Of the other methods, the condensing or total-heat method, accurate as it is in principle, must be rejected on the ground of the difficulty of making the observations with the necessary accuracy.

Putting aside some other methods which are almost untried, and which hardly promise to be convenient, there remain two methods only of determining the dryness of steam, which seem to fulfil the necessary conditions. These two methods are the wire-drawing

method and the separating method. For either of them very convenient apparatus has been arranged, and the observations to be taken are simple.

Tests of the Wire-drawing Calorimeter.—This apparatus is so easily used, and gives indications of such great delicacy, that it seemed desirable to get a direct test of its trustworthiness by using a sample of steam, about the quality of which there could be no doubt. Especially was it desirable to ascertain whether the small loss of heat by radiation caused any appreciable loss of temperature in the steam in the second or superheating chamber. It occurred to the author to superheat a sample of steam on its way to the wire-drawing calorimeter, and to observe whether the change of temperature in the instrument corresponded with that which should occur according to calculation from the quantities of heat concerned. A small superheater was constructed, heated with gas jets. The steam being passed through this, there was superheated steam in both chambers of the instrument.

Let p_1 be the pressure in the first chamber A, Fig. 5, Plate 4, before wire-drawing; t_1 the corresponding temperature of saturated steam; t'_1 the actual temperature of the steam. Then the steam entered the instrument with $t'_1 - t_1$ degrees of superheat. Let p_2, t_2, t'_2, be the corresponding quantities for the second chamber B. Then after wire-drawing the steam has $t'_2 - t_2$ degrees of superheat. Since the total heat per pound is the same for the steam passing through both chambers, if radiation is neglected, and if the frictional eddies are destroyed,

$$1082 + 0\cdot305\, t_1 + 0\cdot48\,(t'_1 - t_1) = 1082 + 0\cdot305\, t_2 + 0\cdot48\,(t'_2 - t_2)$$

$$t'_1 - t'_2 = 0\cdot3646\,(t_1 - t_2)$$

The quantity $t_1 - t_2$ can be found from the observed gauge-pressures; and the observed $t'_1 - t'_2$ can then be compared with the value here calculated. Several tests were made in the laboratory of the Central Technical College, in all of which the observed and calculated values of $t'_1 - t'_2$ agreed very closely. This shows that the effect of radiation in reducing the temperature in the second chamber B is very small. Probably this is due to the fact that the heat lost by

radiation is small compared with the amount of heat passing through the apparatus. In Fig. 7, Plate 6, are shown curves drawn for one of these tests. The steam was taken from a steam-pipe supplying an engine from a Babcock and Wilcox boiler. The engine was running, and the steam pressure was taken by a Schaeffer and Budenberg gauge, and can therefore be approximately accurate only. The mean superheat in the first chamber A was 24°; that in the second chamber B was 80·1°. The mean observed difference of temperature in the first and second chambers was 30·78°, and the value calculated from the above formula was 31·45°, showing a loss, if the pressure observations are assumed accurate, of only 0·67°, possibly due to radiation. But one per cent. of moisture in the steam would have caused a lowering of temperature in the second chamber amounting to about 20°. Even therefore when used without any correction for radiation, it would appear that the wire-drawing calorimeter gives results accurate within about one-tenth of one per cent. of moisture, provided that a fair sample of steam is obtained. Hence it appears that practically radiation may be neglected, and that for steam initially wet the equation in page 39 may be used.

Test of the efficiency of a Separator.—The Barrus calorimeter which the author obtained from America has a separator C, Fig. 5, Plate 4, which can be used in conjunction with the wire-drawing part of the apparatus. This separator does not seem to be quite so well arranged as that of the Carpenter calorimeter; but it occurred to the author that it might be useful to observe how far the separator trapped the moisture of the steam, and what fraction passed on to the wire-drawing aperture. In three tests made at the Central Technical College, the separator trapped from 4·4 to 9 per cent. of moisture, and the steam passing through the wire-drawing aperture showed only from 0·4 to 0·2 per cent. of moisture. It would appear therefore that even with very moist steam the separator alone will give results not erring by 0·5 per cent. of moisture. In the Carpenter calorimeter, Fig. 1, the current of steam is slower, and the separator is steam-jacketed, and the author thinks its action is more perfect. According to Professor Carpenter's results already

mentioned, the action of the separator is practically so perfect that it traps all the moisture.

Tests of a Wire-drawing and Separating Calorimeter side by side.—The author has tried the two calorimeters side by side, the steam current dividing at a T piece to flow to them both alike. In these tests the results by the two methods agreed fairly well, but the wire-drawing calorimeter showed rather more moisture than the separating calorimeter. The former used much more steam than the latter; and the author thinks it possible that a rather larger percentage of moisture was carried away by the stronger current at the T piece. An incidental result in making these tests was interesting. The steam was taken from the engine steam-pipe to the calorimeters through a branch pipe about 30 feet long, which was covered with Keenan's composition. When the separating calorimeter was used alone, the steam showed 13·82 per cent. of moisture. When both calorimeters were in use together, the steam showed only 3·93 per cent. of moisture. The difference appears to be due to radiation from the 30 feet length of steam pipe: with the very small current required for the separating calorimeter, the condensation due to radiation produced a considerable effect; with the much faster current required for the two calorimeters used together, the effect of radiation was much less. So must it be in the working of steam stations: when the engines are working at full power, the effect of radiation in producing moisture in the steam is not serious; but when the engines are working with a small load, the amount of moisture produced by radiation is much more considerable in proportion to the weight of steam used. This is no doubt one cause of inefficiency when engines are worked with small loads.

In Fig. 8, Plate 7, are shown the observations taken during a boiler test with a wire-drawing calorimeter. The boiler was a Babcock and Wilcox boiler, and the observations were made at the Central Technical College. The steam valve to the calorimeter was opened at 11.25 A.M., and the readings of the two thermometers commenced at 11.55 A.M., and were taken about every $2\frac{1}{2}$ minutes till 1.15 P.M.

The observations it will be seen were extremely consistent throughout; and they showed a mean of 1·23 per cent. of moisture in the steam.

Conclusion.—Generally the author thinks that the wire-drawing calorimeter without separator is the most convenient and accurate for steam with less than about 2 per cent. of moisture. For steam containing more moisture, the separating calorimeter without wire-drawing apparatus is accurate enough and convenient. The use of the separator and wire-drawing calorimeter combined is more troublesome, especially if, as is desirable, a condenser is also used to determine the amount of steam passing through the separator. In cases where there is much priming, it would seem best to take the whole of the steam through an ordinary steam-separator, measuring the amount of water trapped; and then to test by a wire-drawing or separating calorimeter the dryness of the steam after passing the separator. In priming, much of the water probably flows along the bottom of the pipe, and it appears impossible that a sample can be obtained containing an average proportion of steam and water. It is recommended by Professor Carpenter that the sample of steam to be tested should always be taken from a vertical not from a horizontal steam-pipe. No doubt there is rather more tendency for water to flow along the bottom of a horizontal pipe than down the sides of a vertical pipe; but merely taking steam from a vertical pipe does not ensure freedom from error, especially if the amount of moisture in the steam is considerable. Variations in tests for wetness are doubtless often due to the difficulty of getting a true average sample of steam; and it would seem that errors are generally in the direction of under-estimating the amount of moisture.

Discussion.

Professor UNWIN said the paper contained in page 32 an explanation of how it came to pass that he had last year prepared a report for a Committee of the British Association on the methods of determining the dryness of steam. Some time afterwards the

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President had been good enough to ask him to write a paper on the same subject for this Institution. He had pointed out to the President that he had already said all he was able to say on the subject; but the President appeared to be of opinion that nevertheless a discussion at the Institution of the questions involved would be useful. Some of the forms of apparatus described in the paper were exhibited, including both the Carpenter separating calorimeter, and the Barrus separating and wire-drawing calorimeter combined, which he had obtained from Mr. Barrus himself. The separating portion of the apparatus, which was here attached to the wire-drawing portion, was not always used. The Globe calorimeter, also shown, was exactly like the Barrus in principle, only that the whole instrument was packed inside a cylindrical case in rather a neat way.

The curves drawn in Fig. 7, Plate 6, had been obtained with the use of superheated steam, which was therefore steam of a known quality; they thus formed a test of the validity of the indications given by the wire-drawing calorimeter. The nearly straight horizontal dotted line B showed the saturation temperature of the boiler steam corresponding with its pressure. The top line S showed the actual temperature to which the steam was superheated on its way to the calorimeter, before the wire-drawing took place. The lower line W showed the actual temperature found after the wire-drawing of the steam into the second chamber of the calorimeter. Almost coincident with this line W there ran a dotted line C, which showed what, according to calculation, should have been the temperature in the second chamber, on the assumption that the steam had originally the degree of superheating represented by the top line S. It was seen that there was practically no difference between the two lines W and C, except the little that was due to the lag of the thermometers in taking up the temperatures of the two chambers.

The whole question of the best method of determining the dryness of steam he could not hope had been solved in the paper; but the history of the subject had perhaps been brought out rather more clearly than before. Some of the earlier experiments, as early

even as 1856, appeared to be but little known. Some steps had been taken, which he thought would not be reversed, in deciding the conditions that must be maintained in accurate observations on the dryness of steam; but one point especially had not been treated, to which he desired to draw attention. A large part of the difficulty in determining the dryness of the steam used by an engine lay in obtaining a fair sample of the steam. On this point he had hoped to make some experiments before writing the report for the British Association, but he had not succeeded in making any that were conclusive; and although he was well aware how important a point this was, it had been referred to only in the most incidental way, either in the original report or in the present paper. It did not indeed affect the conclusions respecting the relative value of the several calorimeters; it was a matter which lay beyond that, and which would require further experiments. During the last few weeks it had come to his knowledge that Professor D. S. Jacobus of Hoboken had been making some important experiments on this point. An ordinary way of getting a sample of steam was to have a collecting pipe projecting transversely into the main steam-pipe, with a dozen or more holes. It was assumed that this number of holes would amongst them collect a fair sample. Although he had sometimes used that method, he had never liked it at all, and had never trusted it. Professor Jacobus had now tried it in a rather extreme form, by putting right across a 3-inch main steam-pipe a $\frac{1}{2}$-inch collecting pipe, stopped up at the end, with a dozen 3-16ths inch holes in it. He found that, with a sharp current of steam across the collecting pipe, a good deal of the moisture in the steam passing along the main pipe impinged upon the surface of the collecting pipe, adhered to it, and was sucked in at the holes, so that the sample contained from $1\frac{1}{2}$ to 3 times as much moisture as it ought to have done. Though he had not had time to examine these difficult experiments carefully enough to feel sure that the results would bear general application, he knew that Professor Jacobus was a careful experimenter, and he had no doubt the general conclusion was right, that by collecting steam in that way an indication was obtained of excessive moistness. At present he was

(Professor Unwin.)
himself hoping rather to find a solution of the problem by inserting in the centre of the main steam-pipe a small nozzle facing the current of steam flowing along the pipe. The best sample of steam he thought would be got by using a very small nozzle so proportioned that the velocity of the steam entering into its single opening should be about the same as the general velocity of the steam along the main pipe. This was a condition which he thought not impossible to realize; and he believed that in this way a fair sample of steam would probably be obtained.

Mr. MICHAEL LONGRIDGE, having suggested some ten years ago to another institution that it would be well if a prize were to be offered for a paper or experiments which should enable engineers to determine this particularly knotty question, hailed with the greatest satisfaction the paper now read. The fact that it was possible to determine with almost entire accuracy the quantity of moisture in steam was a matter of congratulation; but, as just pointed out by the author, only half the work had been accomplished as yet, and it remained to determine how best to obtain the sample of steam to be examined. This in his opinion was the most difficult part of the matter; and it seemed to him that for practical engineers the solution of the question of the dryness of steam lay not in any of the small apparatus described in the paper, but, as suggested by the author in page 47, in an ordinary steam-separator, which should separate the water from the whole of the steam used in the engine. If this plan were adopted, it became important to decide what area was required in the separator, so that the steam might deposit the whole of the moisture which it drew along with it. On this point the paper was almost silent. In the author's report to the British Association last year however, some results had been given of combined separator and calorimeter trials (page 20 or 411), which threw some light upon it. In those experiments about 55 lbs. of steam at 68 lbs. pressure above atmosphere were condensed in an hour: that is, about 4·77 cubic feet of steam passed through the separator per minute. Judging from the drawi g, the area of the cross section of the separator traversed by the steam appeared to

be about $3\frac{1}{2}$ square inches. If that were the case, the velocity of the steam through the separator would be somewhere about $3\frac{1}{4}$ feet per second. It appeared then that at $3\frac{1}{4}$ feet per second the water could be separated from the steam; but it was obvious that, in order to get so low a velocity as $3\frac{1}{4}$ feet per second with a large engine, rather a large separator would be required. The question then was, how much could the velocity be increased? Though unable to answer this, he might mention two experiences which might help towards an answer. The first was with a Cornish boiler 5 feet diameter by 15 feet long, working under atmospheric pressure and evaporating about 1,000 lbs. of water per hour. The water surface was about 66 square feet; and the steam, about 7·3 cubic feet per second, escaped into the air through an open manhole about 1·4 square feet area, and also through a steam dome having an opening of about 0·2 square foot at the top and communicating with the boiler by a hole of about 0·87 square foot in the boiler shell. When all the steam escaped through the manhole, no water came with it; but when the escape was only through the dome, a continuous shower of small drops was thrown into the air. Here the velocity through the manhole would be about 5·2 feet per second, through the opening into the dome about 8·4 feet per second, and through the hole in the top of the dome about 36 feet per second. The second experience occurred in attempting to drain the jacket of the cylinder of a horizontal steam engine through the same pipe that supplied the steam to the engine. The pipe, which was $1\frac{1}{2}$ inch bore, was led vertically downwards from the bottom of the jacket for a few inches, and then horizontally for about 3 feet, where it branched into two: one branch, through which live steam was supplied, rose vertically; the other branch, through which the water was supposed to drain away, fell towards a steam trap. The pressure in the pipe was about 90 lbs. per square inch; and with this pressure it was found that, so long as the velocity of the steam in the pipe was kept down to about 5 feet per second, the water would drain against the current; but if the velocity became greater, the water could not escape, and gradually filled up the jacket. Now the force which carried the drops of water out of the Cornish boiler dome, and reversed the

(Mr. Michael Longridge.)
flow of the stream of water in the jacket drain, was the friction of the steam upon the surface of the water; and the figures he had mentioned seemed to show that this friction increased, as would be expected, with the pressure of the steam; for, while the pressure was the atmospheric pressure, a current of 5·2 feet per second was insufficient to carry drops the size of dust-shot; but when the pressure rose to 90 lbs., a current of practically the same speed sufficed to carry a small stream of water back into the jacket. Had the water been in the form of small drops having a comparatively large surface per unit of weight, a much slower current he believed would have prevented the draining of the jacket. Assuming however that a velocity of 5 feet per second was allowable, he thought it would be practicable, by means of a separator in the steam pipe, to dry the whole of the steam required even for a large engine. A 1,000 H.P. engine for instance would take say 15,000 lbs. weight of steam per hour at 120 lbs. pressure above atmosphere, or about 13·7 cubic feet per second. Hence a separator having 2·8 square feet of sectional area ought to suffice to dry the steam, provided it were so constructed that the drops of water would be guided to unite with one another into little rills, and the rills again into one or more streams, so that the surface of the water might be diminished as much as possible in relation to its weight. These streams should be carried down to the bottom of the separator, as far as possible without change of direction; while the direction of the current of the steam should be reversed. With these precautions he thought it would be quite possible to construct a separator of moderate size for engines of the highest powers; and he would suggest that some of those who had the means should make experiments with various forms of separators, testing by the throttling calorimeter the steam which had passed through them, and should report the results to the Institution.

Mr. Bryan Donkin, Member of Council, noticed that the author had properly distinguished between the moisture contained in the steam as it came from the boiler, and that in different parts of the steam pipe, and especially that in the steam near the engine, all of

which probably varied. If a research committee were to be appointed to investigate this question of the moisture in steam, under the chairmanship of Professor Unwin, he thought it would be a highly advantageous step. As an addition to the history of the subject, mention might be made of the large number of experiments carried out with fixed locomotive boilers by the late M. Henry on the Paris Lyons and Mediterranean Railway, of which an elaborate description was given in the "Annales des Mines," vol. 6, 1894, pages 119–234. A continuous condensing calorimeter was employed for determining the priming water; and it appeared that in M. Henry's opinion this was the only reliable method, because in the other instruments hitherto used the steam was mechanically separated from the water, and hence it could not be known with certainty whether it was perfectly dry. An ascertained quantity of the steam to be tested was passed into a small surface-condenser, and there completely condensed. For a given weight of this mixed steam and water the increase of heat in the condenser was measured. The more water there was in the mixture, the less was the quantity of heat given to the condenser. The apparatus might be worked either intermittently or continuously, and in the experiments it was arranged to work continuously. On the steam pipe conveying the steam from the boiler to the atmosphere a small pipe was placed, about $\frac{1}{2}$ inch internal diameter, leading to the surface condenser through a throttle valve, which regulated the flow of steam. On the boiler side of the valve the steam was at boiler pressure; on the other side and in the condenser it was at atmospheric pressure. The steam was condensed inside the condenser tubes, outside which the cooling water circulated. The quantity of circulating water passing through the condenser per second was constant, as was also the quantity of steam passing through, the pressure in the boiler being uniform. The condenser was large enough to condense the whole of the steam admitted into it. Every quarter of an hour three temperatures were taken, (1) of the steam before it entered the condenser, (2) of the cooling water before entering, and (3) of the water resulting from the condensation of the steam. To measure the quantity of the cooling water it was passed alternately into two

(Mr. Bryan Donkin.)

large tanks provided with gauge-glasses. The condensed water was led alternately into two receivers and weighed; its weight was equal to that of the steam tested, including the priming water it contained. The quantity of heat entering the condenser was evidently equal to the quantity of heat leaving it, since the operation was continuous and the temperatures were constant. If those two quantities of heat were expressed as an equation, the percentage of priming water might be obtained from it. One conclusion from these experiments was that when the steam was taken out of the steam dome it was much drier than when taken lower down in the boiler; the average he believed was only 3 or 4 per cent. of moisture in the steam taken from the dome.

Another plan, arranged by Herr Gehre of Düsseldorf, for measuring the quantity of priming water, was illustrated in Fig. 9, Plate 8. Part of the steam from the main steam-pipe S passed through the short pipe P of $2\frac{1}{2}$ inches diameter, on which were two valves for shutting off a portion of the steam after a large quantity had passed through. In this way a fair sample of steam was obtained. It was necessary of course that the two valves should be absolutely steam-tight. On the top of the pipe P a thermometer and a pressure-gauge were fixed. At the moment when the sample of steam was isolated in the pipe, the readings of these instruments agreed with each other according to the tables of saturated steam. The pipe was then heated from below by a number of flames, and the readings were again noted. If there was no moisture in the steam, the thermometer would at once begin to show a temperature higher than that corresponding with the pressure of pure saturated steam; if the contrary was the case, the steam while increasing in pressure would continue saturated until the moisture was completely evaporated; and the pressure was noted at which superheating then commenced. The dryness fraction would accordingly be the ratio of the specific weights of the steam at the two pressures noted, namely at the moment of isolation and at the commencement of superheating.

In any future experiments he would suggest that samples of steam should be taken from the boiler at heights of 1 inch, 3 inches,

6 inches, and 12 inches above the water level, and even 2 feet above if possible: not only from a Lancashire boiler with a large water surface, but also from a vertical boiler with a small water surface, so that the results might be compared.

Mr. DRUITT HALPIN said a great deal of trouble had been taken with the experiments made on boilers for the Paris Lyons and Mediterranean Railway, referred to by Mr. Donkin, which formed one of the most elaborate series of experiments that had been carried out with locomotive boilers in modern times. Although they might have brought out a great many facts, he certainly thought they did not throw any light on the chief subject enquired into, judging from the way in which they had been conducted; and while he did not mean that no data could be obtained from them, he believed that no data had actually been furnished in regard to priming, when condensing the whole of the steam. It was only when working on a small scale, he understood, that the results mentioned by Mr. Donkin had been obtained; and when it was also tried to condense the whole of the steam, all the results he believed had been rejected as unsatisfactory.* Whether that was owing to the thermometers not being fine enough, he could not say; in page 43 of the paper the author had himself rejected the condensing method, accurate as it was in principle, on the ground of the difficulty of making the observations with the necessary accuracy.

With regard to the separating method described in page 34, the idea had struck him that it might be possible to carry it out by a centrifugal separator, like that employed for separating cream from milk in virtue of their different specific gravities. If the whole of the steam with its priming water were made to pass through such a separator on its way to the engine, it occurred to him that, in the same way as in the case of milk, the whole of the water ought to be thrown off, and could be collected in a circumferential trough, whence it could be drawn off and weighed. It would of course

* Zeitschrift des Oesterreichischen Ingenieur-und-Architekten-Vereins, vol. 42, 1890, page 129. Zeitschrift des Vereines Deutscher Ingenieure, vol. 36, 1892, page 70. Annales des Mines, vol. 6, 1894, page 136.

(Mr. Druitt Halpin.)
be necessary to make some correction for the amount of superheating due to the mechanical work put into the water by the revolving wheel.

Professor T. HUDSON BEARE, referring to the condemnation passed upon the salt test in the paper, agreed that the results obtained from it tended to throw considerable discredit upon it, and that at best it showed only the mechanical priming, and could not possibly show what amount of wetness was present in the steam in consequence of radiation. At the same time he thought the salt test might be used as a valuable accessory to the calorimeter, if priming did occur. The calorimeter indicated only that the steam had a certain amount of wetness; it did not show where it came from:—whether it was mechanical priming which might be remedied by alterations in the boiler; or whether it was owing to radiation losses from the top of the boiler, or in the pipes and stop valve through which the steam had passed before the sample had been drawn off. The salt test he thought might well be used for the purpose of helping to analyse the facts, and to decide the real causes of priming.

Respecting the results given in page 45 from the tests of the wire-drawing calorimeter, he should be glad to know whether the pressure gauges used were tested either beforehand or afterwards; because the calculated temperatures, and therefore also the differences between the observed and the calculated temperatures, depended upon the accuracy of the gauges. It was stated in page 39 with regard to the wire-drawing method that no weighing was required, and that temperatures only had to be observed; and he enquired whether in that calorimeter it was necessary to have a pressure gauge attached to the second chamber, in order to determine whether the pressure in this chamber was atmospheric; in page 38 it was said to differ little from atmospheric.

Professor UNWIN replied that the pressure gauges used in the experiments in page 45 had been tested, but he did not rely upon them very much. There was a difficulty, he admitted, and he was afraid there always would be, with calculations taken from pressure

gauges; but he could use nothing else. For ascertaining the pressure in the second chamber of the wire-drawing calorimeter, it was strictly necessary to employ a small mercury gauge or a water gauge, unless there was a large and free opening for discharge into the atmosphere; when this was the case he had found that the difference from the atmospheric pressure was so small that it might be disregarded.

Professor BEARE considered that the difficulty of obtaining fair samples of the steam to be tested, to which allusion had been made at the very end of the paper (page 47), lay at the root of the whole matter; and it might be possible he thought to test the best arrangement for collecting the samples. If on the steam pipe were placed a separator big enough to take off the whole of the water passing through the pipe, and if before arriving at the separator a number of collecting pipes were put in to different depths, of the shape suggested by Professor Unwin and all in use simultaneously, some clue might be obtained as to the best way of getting true samples of steam. By merely drawing out small samples from the side or centre of a large steam-pipe, he doubted whether true samples could be got, owing to the disturbing effect of the mere presence of the collecting pipe.

In this connection it might perhaps be worth while to mention an incident that had just come under his observation in the experimental boiler at University College, which was a locomotive boiler with a wet-bottom fire-box. In Fig. 10, Plate 8, was shown a longitudinal section through the steam space. The steam was drawn off to the engine through an internal pipe A, which had a number of small holes along the top end. At the beginning of last week the boiler had been opened for inspection, and then closed again. An engine trial was made on the Friday, the results of which differed greatly in consumption of steam from the results of previous trials. The engine itself showed in its working during the trial that there was a large quantity of water present in the steam; and all the indicator cocks showed also a large quantity. The only explanation seemed to be that priming must have occurred to a large extent. On Saturday the boiler was opened again, and the cause was then traced to a mishap with the internal steam-pipe. The manhole had been

(Professor T. Hudson Beare.)

put in rather an awkward position on the boiler; and it was found that, in putting the manhole cover on again after the inspection, the flange of the steam-pipe had been displaced, and the pipe itself had thereby drooped down into the position shown dotted in the drawing, but as far as could be made out the orifices were still above the water level. The pipe being then lifted back into its proper position, another trial was made on Monday, when no water showed itself and the whole of the trial was in accordance with those regularly made. The difference was extraordinary. In the Friday's trial, when the priming occurred, the total water and steam passing through the cylinder per hour was 378 lbs.; in Monday's trial it was 154 lbs., with exactly the same speed, the same steam pressure, and the same power. This accidental experience showed how priming might occur without the reason being known; and it might also throw light upon the extraordinary priming which had taken place in one of the marine engine trials (Proceedings 1894, page 46). Although in that trial he did not suggest that the steam had been drawn off so close to the water as in last week's experience, yet, if the water had been tossing about and thrown into foam by the motion of the steamer, it was quite possible that as large an amount of priming might have occurred as in that particular voyage had been suspected to have taken place.

Mr. Thomas Clarkson agreed that the mode of taking a sample of steam was a matter of great importance; for if the sample was not accurately taken in the first instance, not much reliance could be placed upon the results of the subsequent measurements. Perhaps therefore it might be interesting in connection with these experiments to refer to the progress that had recently been made in automatically sampling ores and minerals. The sampling, as all mining engineers knew, was a matter of great importance, and formed the basis of the whole determination of values. It had now been brought to a high degree of precision; and he thought it was possible that the same principle might be applied to solve the present difficulty. The apparatus employed consisted of a hollow cone or hopper, mounted vertically so as to rotate with its truncated apex downwards; and into

the open bottom was inserted the upturned apex of a solid cone, leaving a narrow annular space all round between the two. The pulverised material fed into the revolving hopper issued in a revolving stream through the annular orifice at bottom, and was distributed beneath in a concentric annulus. In this annulus the rotating hopper secured a uniform distribution of the stuff all round; and though it might not possess uniformity radially, this was unimportant, since, if a true sector were taken out of the annulus. so long as the two bounding edges were truly radial it was immaterial how the stuff might be distributed radially in the annulus. This simple method had been tested over and over again, and was now used extensively for sampling materials in mining and other operations. Other apparatus had been used for automatic sampling; but the method of taking a true sector in duplicate from an annular revolving stream of the material had proved to be the only reliable one in all cases; and it appeared to be scientifically correct. It occurred to him therefore that it might possibly be useful in the present case, as it had proved so useful in others. If some similar conical arrangement could be attached to the steam-pipe for producing a revolving annulus of steam, from which two small sectors could be taken, this would be a true sample of the whole of the steam.

Mr. R. E. B. CROMPTON considered the dryness of steam was a matter of the utmost importance to mechanical engineers who had large establishments for the supply of power, from which they had to obtain an income principally by turning coal into electricity. Great losses had long ago been found to occur through water being present in the steam-pipes; and it became necessary to ascertain whether that water was due to priming of the boilers or to condensation in the pipes. No satisfactory method he was sorry to say had yet been pointed out, by which this question could be so far determined that the due proportion of blame could be assigned to the boilers, or to the steam-pipes, or to the covering of the steam-pipes as far as concerned its efficiency in preventing condensation in the pipes. The real requirement for engineers was not quite the steam-

(Mr. R. E. B. Crompton.)
separator mentioned by Mr. Longridge (page 50), which would enable them only to form some idea of the total quantity of water present in the whole of the steam at the particular place where the separator was fixed; but they would like to be able to ascertain the proportion of water in the steam where it left the boiler, and at various points along the steam-pipe, and also along the various branch or duplicate steam-pipes which had to be used in all power stations. For this purpose it was evidently necessary to be able to take samples of steam from the pipes: whether or not by the methods proposed in the paper, he could not say. The suggestion offered by Mr. Clarkson (page 58) appeared to him to have a great deal of right in it, namely that it must surely be possible to put into the steam-pipe at intervals some simple form of apparatus, which would cause such a whirling or mixing motion of the steam and of the water carried along with it that a fair sample could be taken off at the point desired, perhaps in the very way which had been described for sampling ores. When once the fair sample was obtained, he was convinced that the method of determining the moisture by the difference of temperatures was the right one; and electrical engineers could easily supply the means of ascertaining the temperatures with the utmost accuracy. Within the last year or two, the pyrometer originally invented by Sir William Siemens, and now called by Messrs. Callendar and Griffiths the platinum thermometer, had been perfected by them to such an extent that it had become a most reliable instrument, and with it temperatures could be read continuously. A large number of temperatures could be read by a single observer, who could read them off one after another with a degree of accuracy previously undreamt of. The platinum thermometer, combined with the wire-drawing method, he was sure would give a means of obtaining the percentage of water in samples of steam to a degree of accuracy that had not yet been attempted. The experiments that had been carried out by the author with the wire-drawing apparatus (pages 44–46) he was sure could be carried out by means of platinum thermometers in a perfectly satisfactory and highly convenient manner; and a great many experiments might thereby be carried on simultaneously.

Professor David S. Capper thought that, in entirely throwing aside the salt test because it afforded a measure of the mechanical priming only (page 43), the author was hardly giving it its due value; for if it afforded a means of distinguishing, though only approximately, between the mechanical priming, and the priming which was due to condensation either at the top of the boiler or in the pipes leading from the boiler, this was additional information of great importance. In the suggestion for a research committee on this subject (page 53) he heartily concurred; and he certainly thought that to spend some of the funds of the Institution in that way would be much better than duplicating a building which was now so freely and cordially lent for their use by the Institution of Civil Engineers.

Mr. George Cawley suggested that an investigation of the advantage of moderate superheating would practically supersede both that of the dryness of steam and also that of the value of the steam-jacket. Moderate superheating he thought got over not only the difficulty from priming, but also the complication of the steam-jacket. The interesting methods described in the paper for determining the dryness of steam, even assuming that the best of them were accurate, dealt after all with only a sample of steam; and so long as this was the case, it seemed to him that the same doubt as at present would still attach to the quality of any steam so tested. It occurred to him that, with an engine of say not more than 100 horse-power, the dryness of the steam might easily be determined by passing the whole of the steam from the boiler through a superheater. The apparatus might stand upon a fire-clay furnace heated by coal gas, much like one of Mr. Thomas Fletcher's laboratory furnaces that were used for melting large quantities of metal; it might contain a nest of vertical tubes, through the inside of which the heat from the gas flame would pass up, while the steam as it came from the boiler would circulate round the outside. The temperatures would be taken by thermometers in the steam-pipe before and after passing the superheater. Assuming that the apparatus was fully large for its work, the passing steam after it had been completely

(Mr. George Cawley.)
dried would undergo some slight superheating before leaving the apparatus; and the amount of superheat would be shown by the second thermometer. Though it might seem at first rather an expensive procedure to superheat the steam by means of a furnace burning ordinary coal gas, yet after all he thought the cost would not prove serious. Supposing there were 10 per cent. of moisture in the steam, and that the engine were taking 2,000 lbs. weight of boiler steam per hour, the gas in the superheater would have to evaporate 200 lbs. of moisture per hour. The weight of coal gas at the ordinary pressure was about 32 lbs. per 1,000 cubic feet; and taking the price at 2*s.* 8*d.* per 1,000, one pound of gas would cost 1*d.* Taking coal at $11\frac{1}{4}$*d.* a cwt., then 10 lbs. would cost 1*d.*; so that, weight for weight, the cost of coal was only one-tenth the cost of gas. But against this, in respect of calorific value, 2 lbs. of gas were equal to 3 lbs. of coal: so that the total cost of the gas burnt in the superheater would probably be not more than six or seven times that of coal. Then if the efficiency of the superheater, which would probably be from 60 to 70 per cent., had been determined beforehand by passing water through it, the moisture in the steam could easily be ascertained within 5 or 10 per cent. of the exact amount passing from the boiler: which, according to the figures given in the paper, would be far more accurate than the salt test or some of the other tests. If the steam after passing through the superheater were saturated steam, only just dry, then the superheater and the boiler together would only be doing what the boiler should be doing itself, namely supplying dry saturated steam. Therefore the relation between the weights of the fuel consumed, turning the gas into its equivalent coal, should give the amount of priming. If W were the weight of the coal used in the boiler, and w the weight of the coal equivalent to the gas used in the superheater, then the dryness fraction of the steam as it left the boiler would be $W \div (W + w)$, assuming that the evaporative efficiencies of the boiler and the superheater were the same, and that the feed-water was fed from an independent source to the boiler, at a temperature equal to that of the moisture in the wet steam. If the feed were not supplied at that temperature, or had

been heated by an economiser attached to the boiler and utilising some of the fuel W, a correction would have to be made for this; and also for any real superheating done by the superheater, in raising the temperature of the steam above that corresponding with its pressure. The advantage of such a plan would be that the entire steam from the boiler would be dealt with, and there would be no need to have any samples at all.

Captain H. RIALL SANKEY noticed that in page 39 of the paper the usually accepted value had not unnaturally been taken for the specific heat of steam, namely 0·48. This value however had been criticised in Mr. Macfarlane Gray's Paris paper (Proceedings 1889, page 399), in which had been brought forward certain experiments of Regnault's to substantiate the criticisms offered. The late Mr. Willans some short time before his death had been engaged in correspondence with Mr. Gray on this very subject of moisture in steam. In connection with the present paper he had looked into the correspondence, and had there found a formula given by Mr. Gray for the specific heat of steam, which, although it did not appear in the Paris paper of 1889, was directly deducible therefrom: namely $0 \cdot 38976 + [6 \cdot 9556571]\, p \div \sqrt{\theta^7}$, the number in brackets being the common logarithm of the numerical coefficient. This gave the value of the specific heat according to the usual definition at the absolute temperature θ in degrees Fahr. and at the absolute pressure p in lbs. per square inch; and it showed that the specific heat was not a constant, but varied according to the absolute pressure p of the steam and its absolute temperature θ. The amount of variation was not great, but would be appreciated better by means of the following numerical examples. For saturated steam at an absolute pressure of 163·3 lbs. per square inch, which corresponded with the temperature of 365° Fahr., the specific heat according to the above formula was 0·481. If the steam was now superheated at constant pressure until the temperature rose to 400°, the specific heat dropped to 0·469. For saturated steam at atmospheric pressure of 14·7 lbs. per square inch and temperature 212°, the specific heat was 0·407; and on superheating at that pressure up to 292°, or 80° of superheat, the

(Capt. H. Riall Sankey.)
specific heat fell slightly to 0·401. Substituting corresponding values in the equation given in page 41 of the paper, he made out that the loss due to radiation and eddies (page 39) in the second chamber of the wire-drawing calorimeter was about 6° ; and this did not appear unreasonable. These calculations however were only approximate, in consequence of his not having the exact values of the temperatures.

[Since the meeting the necessary data have been obtained from the British Association Report (1894, page 410), and the means of the readings there given are found to be as follows :—

First superheating vessel	absolute pressure 69·15 lbs. per square inch. absolute temperature 785·3° Fahr.
Second superheating vessel	absolute pressure 15·6 lbs. per square inch. absolute temperature 754·5° Fahr.

These data can be examined by a formula of Mr. Macfarlane Gray's, given originally in his Paris paper (Proceedings 1889, page 432), which, when converted into degrees Fahr. and lbs. per square inch, becomes for the total heat, including the heat possessed by the substance at the temperature of melting ice,—

$$\text{Total Heat} = 1{,}399 + 0\cdot39\,(\theta - 9\cdot27 \times 10^6 \times p \div \sqrt{\theta^5}).$$

If θ_1 θ_2 and p_1 p_2 be the absolute temperatures and pressures in the first and second superheating vessels respectively, it is evident that, since the total heat per pound of steam is the same in both chambers, assuming no radiation and no eddies and neglecting energy of translation,

$$\theta_1 - 9\cdot27 \times 10^6 \times p_1 \div \sqrt{\theta_1^5} = \theta_2 - 9\cdot27 \times 10^6 \times p_2 \div \sqrt{\theta_2^5}.$$

Substituting 785·3° for θ_1 and 69·15 lbs. for p_1 as given above, it is found that the left-hand side of this equation is equal to 747·4° Fahr. Clearly therefore θ_2 must be greater than this value—say 755°. Substituting the latter for θ_2 and also 15·6 lbs. for p_2, the value of $9\cdot27 \times 10^6 \times p_2 \div \sqrt{\theta_2^5}$ is found to be 9·23°. Hence $\theta_2 = 747\cdot4 + 9\cdot23 = 756\cdot6°$. The experimental value being 754·5°, it thus appears that, according to Mr. Gray's formula, 2·1° Fahr. is the loss due to radiation and eddies.]

In this connection Mr. Gray and Mr. Willans had jointly devised a superheater, similar to the Barrus calorimeter, but differing from it in that the steam in the superheating chamber was not expanded

down to atmospheric pressure, but only to such a pressure as was sufficient to give a few degrees of superheat: just sufficient superheat in fact to ensure that all the moisture in the original steam was evaporated, the idea being practically to eliminate the effect of any possible error in the value of the specific heat of steam. As far as he knew however Mr. Willans had not arrived at any satisfactory result. During the last few days he had himself made some further experiments with this instrument; and the conclusion he had come to was that the difficulty of measuring the temperature prevented the apparatus from being used successfully. The bulb of the thermometer in the superheating chamber could not be exposed directly to the steam, owing to the pressure, but had to be enclosed in a metallic capsule, and consequently the true temperature of the superheated steam was difficult to obtain, and it took a long time for the thermometer to become steady. In this respect the Barrus calorimeter had an advantage, in that the bulb of the thermometer could be directly exposed to the steam.

In judging of the calorimetric experiments made by Mr. Willans, it should be borne in mind that the object had been to ascertain whether the quality of the steam supplied to the engine during the trials was sufficiently near to that experimented upon by Regnault, for enabling his results to be used in the calculations of the engine efficiencies. From this point of view the several calorimetric determinations in page 37 should be looked upon as separate measurements of the same quantity; and omitting the two lowest results 0·9638 and 0·9646—because in one of these experiments the steam had been blown into warm water, and in the other it had been blown very fast into the water—it would be seen that the remaining determinations agreed to within less than one per cent. of the mean. Such a degree of accuracy confirmed the author's remark (page 37) as to the care with which these experiments had been made; and in this connection it might be pointed out that Joule's most careful experiments on the determination of the mechanical equivalent of heat had been discovered to be one per cent. in error.

As regarded the scale of these experiments, while Mr. Willans had undoubtedly been partial to experiments on a large scale, in this

(Capt. H. Riall Sankey.)
instance the scale had been fixed by the necessity of blowing the steam into the water at the maximum rate required in the engine trials: unless indeed a sample only had been experimented upon, in which case a doubt would have arisen as to whether the sample fairly represented the quality of the steam.

Professor ARCHIBALD BARR was sure the present paper would be of lasting value to all engaged in experiments of this kind. He was glad to find the author had spoken rather severely against the salt test; for he himself thought it was not at all a reliable test. The difficulty of obtaining an average sample of the boiler water, which had been mentioned in page 42 in condemnation of the method (*a*), applied quite as strongly to the method (*b*), in which a sample of steam coming from the boiler was taken. Sometime ago he had had occasion to look into the possibility of applying the salt test to a water-tube boiler of particular construction; and it had appeared to him then certain that this test would be utterly unreliable, because it could not be known from what part of the boiler any particular sample of steam came, or rather from what part of the boiler the entrained water came, or what proportion of it came from different parts of the boiler; and from the arrangement of the boiler it seemed certain that the salt would be a great deal more concentrated in one part of the boiler than in another. Therefore the salt test would be entirely unreliable, even though samples of water were taken from different parts of the boiler. The sampling of steam, which had been dealt with by the author in his subsequent remarks (page 49) and also by some other speakers, was the basis he believed of the whole subject. In discussing the ordinary method of obtaining samples by means of a perforated pipe, the author had referred (page 49) to the probable flow of water over the surface of the pipe, whereby a wetter sample might be got than ought to be obtained. Another reason why a fair sample was not likely to be so obtained was that, if the particles of water were of any appreciable size, they would have greater inertia than an equal volume of steam; and therefore, if the flow through a collecting orifice exposed to such a stream were slow, in all probability too wet a sample would be got; and if the

flow through the orifice were too quick, steam would be drawn in from around the orifice without a corresponding amount of water being drawn in, and therefore too dry a sample would be obtained. The method proposed by the author for obtaining a true sample (page 50) had also been proposed by himself about a year ago in discussing this subject at the Institution of Engineers and Shipbuilders in Scotland (Transactions, vol. 37, 1893–4, page 112): namely that a collecting pipe should be arranged with sharp-edged nozzles facing the current of steam, and that great care should be taken that the ratio of the volume per minute of the sample to the volume per minute of the bulk of the steam passing on along the steam-pipe should be the same as the ratio of the area of the nozzles to the remaining area of the steam-pipe section. Nevertheless he was afraid that this proposal did not wholly meet the difficulty, because it seemed certain that when a particle of water got into contact with the side of the pipe it would stay there; and therefore it would be necessary, as another speaker had pointed out (page 59), thoroughly to mix the steam and water before taking the sample out by this method. By passing the whole of the steam through an arrangement of orifices which would thoroughly mix it and eliminate any flow of water along the sides of the pipes, a much better sample he thought would be obtained than by the ordinary method. One of the best plans he considered was to separate the whole of the water from the steam, which Mr. Halpin had suggested (page 55) could be done by an arrangement of a centrifugal fan. It was done in a tolerably satisfactory manner he thought by the centrifugal separators now in use; but a new kind of separator had just occurred to him as likely to be of value, consisting simply of a spiral steam pipe, through which all the steam would flow on its way from the boiler to the engine. Curiously enough the water should be drawn off from the inner side and not from the outer side of the spiral; because in any spiral pipe, through which steam or any other fluid was flowing, there must be a general flow outwards in the body of the stream, and a more rapid inward flow close to the solid walls, as in the flow of water round river bends which had been so clearly explained in Professor James Thomson's well

(Professor Archibald Barr.)
known papers on this subject.* As soon as the water got to the side of the pipe, it would remain there; and there was no doubt that as it flowed along the walls of the pipe it would work its way round to the inner side of the spiral, and this would accordingly be the place for collecting and drawing it off by suitable arrangements.

Mr. W. S. LOCKHART thought that, if the small nozzle proposed by the author (page 50) to be inserted in the centre of the main steam-pipe had only a circular orifice facing the current, it would simply take off the steam in the centre, where it might perhaps be drier; whereas in order to sample the whole contents of the steam-pipe he considered that the collecting pipe ought to have a flattened nozzle, with a narrow orifice extending right across the steam-pipe diametrically, so as to get the outer steam nearest to the walls of the steam-pipe on either side, as well as that in the centre. Following Mr. Clarkson's suggestion (page 59), perhaps a better way still would be for the orifice, instead of being merely a straight slit with parallel edges, to form a sector of the steam-pipe, extending from the centre to the circumference on one side of the pipe. Supposing the area of such a sector to be one hundredth of the entire area of the pipe, it was obvious that it should sample accurately the quality of the steam passing to the engine, since it would take one hundredth of the outer contents of the pipe, one hundredth of the centre, and one hundredth at every intermediate point.

Mr. JEREMIAH HEAD, Past-President, having been a member of the Committee appointed by the British Association to investigate the various methods of determining the dryness of steam (page 32), wished to say that the whole of the work had really been done by Professor Unwin; and all that the rest of the committee had done was to meet when called together by Professor Unwin, to hear and approve his arrangements. Therefore the whole merit of the highly valuable investigation that had been made rested with the author of the

* Proceedings 1879, page 456. Also Proceedings of the Royal Society, 1876 page 5, and 1877 page 356.

present paper. The mere separation of water from steam, not with any idea of measuring the water but solely with the idea of getting rid of it, was of course a matter of old experience. In many places where there were long ranges of steam-pipes accumulating a great deal of water, it had long been the custom to bend the main steam-pipe down into a receiver: somewhat in the way that was shown in Fig. 5, Plate 4, only that, instead of taking a small collecting pipe out of the main steam-pipe, the latter was itself led down into the receiver, and then the continuation of the pipe ran on from the top of the receiver. That plan took advantage of the fact of water having more momentum than steam; and therefore, when its course was bent down into the receiver, it naturally fell to the bottom and did not rise again. With such a receiver he had known instances where a fire-grate had been added beneath the bottom, for the purpose of re-evaporating the water so separated. Such an addition however he thought was disadvantageous, inasmuch as it involved the necessity of the fire being attended to; and the complication was so great that it was seldom done. In using steam in modern expansive engines, he supposed what engineers really wanted to aim at was that the steam should pass right through from the high-pressure down to the low-pressure cylinder, continuing dry throughout; and that, when it left the low-pressure cylinder for the condenser, it should be just saturated steam, without any moisture and without any superheat. If this result could be attained, it would he imagined be the utmost that could be done with the steam and with the engine. But of course this involved superheating the steam before it was introduced into the high-pressure cylinder. Superheating he believed had been attempted (Proceedings 1894, page 61) by keeping the steam pressure in the boiler considerably above what was intended to be used in the high-pressure cylinder, and then wire-drawing it down before it entered the high-pressure cylinder, so that on entering it had the benefit of a certain amount of superheat. Whether this could be practically done with advantage, he hardly knew. It would of course involve an extra quantity of coal being burnt under the boiler, in order to supply the extra heat which would go right through the engine, and would

(Mr. Jeremiah Head.)

be expended over and above the heat that was in the final dry saturated steam. It could not be kept too clearly in mind that it was the heat which really did the work, and the steam or water vapour was merely the vehicle by which it was conveyed. To the extent that the steam went through the engine as water, and therefore without carrying useful heat, it was a disadvantage in respect of efficiency and economy. It was something like a goods train with its trucks full at starting, which in the course of its journey distributed goods to the various stations at which it arrived, so that towards the end there were some empty trucks which were obviously being taken forwards at a disadvantage.

With regard to the mode of sampling the steam, it was not quite clear to him that the steam in rushing along the steam-pipe carried an equal proportion of water throughout the area. It seemed to have been pretty generally assumed that, if the pipe was horizontal, the water would naturally hug the bottom of the pipe; and therefore the idea of a vertical steam-pipe seemed by common consent to have been arrived at, with the rather implied assumption that any drops of water would then be uniformly distributed throughout the sectional area of the pipe. But if that was not the fact, then a single portion in the middle of the pipe might not contain a fair average of the whole steam. Several ways had already been suggested, all more or less ingenious, for obtaining an average sample; and it occurred to him that possibly there might be yet another way: namely by inserting a sliding or telescopic collecting pipe through a stuffing-box, and having an arrangement whereby it could be gradually worked backwards and forwards across the steam-pipe while the experiment was going on, so that it would test the whole width of the steam-pipe. This might have the effect of producing an average sample, and also of demonstrating whether there was really any difference between the steam in the centre and that at the circumference of the pipe. In a flooded river it would rather be expected that pieces of wood lying along the banks and floated off by the water would be sucked in towards the centre of the stream, where it was running quickest, and for the most part would be kept there. Although that was the case with liquids and solids,

and the present question was concerned with a gas and a liquid, the two cases he presumed would be in some degree analogous; and it was at all events conceivable that drops of water coming along the steam-pipe would be apt to be drawn into the centre, where in all probability the flow of the steam was quickest, because least impeded. He should therefore rather expect that there would be more water in the steam in the centre of the pipe than towards the sides. The contrary opinion he believed had been expressed by Mr. Lockhart (page 68), and how the fact was he did not know; but any plan of the sort he had suggested, if it could be easily arranged, whereby the collecting pipe could be worked in and out across the width of the main steam-pipe, would test this interesting and somewhat important question.

Mr. JOHN G. MAIR-RUMLEY, Member of Council, wished as a member of the British Association Committee upon this subject to endorse the statement made by Mr. Head that the committee were greatly indebted to Professor Unwin for the careful discrimination he had manifested in dealing with the various experiments that had been made by others, and in completing them himself at the Central Technical College. The fundamental difficulty, as had already been stated, was simply that of getting a fair sample of steam. When a fair sample had been obtained, its dryness could be determined within a minute percentage. In his own experience he had been strongly impressed with the importance of taking the water out of the steam before the steam passed to the engine. An instance had come under his own notice a few years ago of a compound engine taking steam from Cornish boilers which were not hard fired. The water was chalk water; and in a trial made to ascertain the amount of the feed-water used by the engine it was found that it used rather over 20·6 lbs. per I.H.P. per hour. Although the steam-pipe was well cleaded, the high-pressure indicator cocks were so full of water that a proper form of diagram could hardly be taken. It occurred to him that the best thing to do would be to put a drain on to the high-pressure valve-boxes. There was a separate valve-box at the top and at the bottom of the cylinder, and drains were put on both,

(Mr. John G. Mair-Rumley.)
and the water was drained into buckets and measured. On the whole trial somewhere about 1,200 lbs. was drained out of 14,000 lbs. of feed-water, or about 8 per cent.; and in addition as much water as could be was taken off through the jackets, by connecting the jacket supply-pipe with the steam main at a place where water was likely to collect. The steam then used by the engine as measured by the feed-water was 17·3 lbs. per I.H.P. per hour, including all the water from the drains. A reduction had thus been made from 20·6 lbs. to 17·3 lbs., which, though nothing like the reduction mentioned by Professor Beare (page 58) from 378 lbs. down to 154 lbs., nevertheless showed how great an advantage it was to separate the water out of the steam before the latter passed through the engine. The best way of doing this he thought was to interpose, as many engineers now did, some form of separator before the steam reached the engine stop-valve. The separator was of course required to be of large diameter, as pointed out by Mr. Longridge (page 52), in order to reduce the velocity of the steam to the speed at which the moisture would be deposited; but after all, if the steam was flowing at only 100 feet per second, a separator six times the diameter of the steam-pipe would give a velocity 1-36th of that in the steam-pipe. On almost all the pumping engines now making at Messrs. Simpson's they were putting a separator just above the engine stop-valve, of a diameter much greater than that of the steam main, so that it might take from the steam main the whole of the water, or as much as could possibly be separated by that means. Recently at the American Society of Mechanical Engineers * it had been suggested by Mr. Charles T. Porter that the steam for the engine should be taken off at right angles to the flow of the steam in the steam-pipe, because then the particles of water were less likely to flow into the engine. With the arrangement he had just mentioned, his firm were doing the same thing; and from the bottom of the separator the steam supplied to the jackets was taken off. In a trial made a short time ago the steam going to the jackets was taken from the engine side of the engine stop-valve. On measuring the quantity of water separated

* "Engineering," 11 January 1895, page 33.

by the separator it was found to be from 4 to $4\frac{1}{2}$ per cent. of the feed-water. This of course was not all priming water; some of it might possibly be due to priming, and the rest arose from the condensation in the steam-pipe. Naturally the steam-pipe was kept as small as possible, agreeably with what was found to be the best practice even if there was a reduction of a few pounds in the pressure, because a small pipe tended to prevent condensation. In the instance of a small steam-pump fixed at the bottom of a well about 200 feet deep, to which a 2-inch steam-pipe had been led down from the boiler at surface, it was found that the pump would not work, the steam cylinder being choked with water; but on substituting a smaller steam-pipe of only $1\frac{1}{4}$ inch diameter, the pump went merrily. There was no doubt that the admission of water with the steam into an engine had a most detrimental effect; and he trusted that the separator described in the paper might be the fore-runner of improved kinds of separators, which would enable the whole of the water to be taken out of the steam, whereby a decided advantage would be gained.

Mr. G. M. Clark thought that, in respect to the determination of the dryness of steam, the needs of engineers were at present ahead of the researches of physicists, with the result that from an engineering point of view none of the methods of measurement proposed in the paper appeared to be completely satisfactory. In designing an apparatus for measuring a new quantity, it was first necessary to consider the properties of the substance to be dealt with, and to select that property which lent itself best to accurate measurement. In the instance of steam the selection was easy, because the properties of steam had not yet been all of them fully worked out, and it was only the thermal constants which were at all well determined. It was thus necessary to use the calorimeter as the standard instrument for determining the dryness of steam, whether the method adopted was of the nature of the salt test or with the aid of a separator; for it was only by comparing the indications of such methods with calorimetric results that the efficacy of the method could be established. The principal sources of error in calorimetric

(Mr. G. M. Clark.)

methods were: firstly, those connected with thermometers; secondly, changes in the specific and latent heat of water; thirdly, the capacity for heat of the calorimeter itself; and fourthly, the gain or loss due to conduction and radiation. Of these, the first two might be relegated to the physicists; for it was their duty to supply reliable thermometers, and also to determine the specific and latent heat of water at various temperatures. The third and fourth sources of error pertained to every calorimeter, whether used in the laboratory or in the workshop. In some particular instances there occurred methods of completely overcoming these two sources of error. Such methods arose when the heat lost in one direction, say by evaporation, was balanced by an equivalent supply of heat from another, as for instance from the electric heating of a coil of wire. In such cases, if the balance was maintained, the calorimeter remained at the external temperature, and no corrections were needed either for heat capacity or for radiation. This therefore was the ideal form of calorimeter which ought always to be employed where possible. The suggested electric heating of a coil of wire was a method of heating which was easily controlled, and which also lent itself readily to simple measurement. It had further to be borne in mind that the quantity to be measured by the calorimeter was the dryness of the steam as it existed in the steam-pipe itself, and not its dryness after it had passed through some length of connecting tubes. Such tubes must always give rise to some uncertainty; and yet it was obvious that they must always be used, unless the calorimeter could be placed inside the steam-pipe. The ideal calorimeter had thus two conditions to fulfil: firstly, it must be in the steam-pipe itself; and secondly, the rate of loss and of gain of heat must be equal, so that the calorimeter should always remain at the same temperature. For realising this ideal it had been suggested by Professor Callendar of Montreal to place inside the steam-pipe a coil of wire, through which an electric current could be passed. The coil was itself to be the calorimeter. It would be gaining heat in one way only, namely by the current passing through it. The loss of heat was more complicated. If the coil was in air, instead of in steam, the loss would be by radiation, conduction, and convection; and the same would be true if it was in steam that

was perfectly dry. But if the steam was moist, then part of the heat would be used up in converting the moisture into steam; and until this was completed there could be no rise in temperature. So long therefore as the heat generated in the coil was insufficient to evaporate all the moisture in contact with it, the temperature of the coil would remain constant; but if the heat generated were gradually increased by increasing the current through the coil, a time would come when more heat would be generated than was required to dry the steam, and the coil would then rise in temperature. The measurement of the rise in temperature was a simple one. The electrical resistance of all pure metals increased as their temperature rose; so that a measurement of the resistance of the coil would show at once whether the temperature was steady or rising. The electrical quantities to be measured were the current, and the resistance of the coil. If a curve were plotted for the resistance with various currents, it would be found that over a certain range the resistance showed little or no change; but after a certain point had been reached the resistance would rise rapidly. That was the point at which the heat generated in the coil was just sufficient to dry the steam. The current at which this change took place would depend not only upon the total quantity of steam passing the coil, but also upon the percentage of water in the steam. There must therefore be provided also the means of determining the total quantity of steam passing along the steam-pipe. An obvious difficulty was the magnitude of the quantities to be dealt with if the whole of the steam had to be dried, which would require a large coil and a considerable current, rendering the whole process cumbersome. But turning to an analogous problem, the determination of the moisture in the atmosphere was effected without collecting the whole atmosphere or even any large part of it; the air was sampled by means of a wet and dry bulb thermometer. In a similar manner he thought it was possible that a strip of platinum foil, placed in a steam-pipe and heated by an electric current, would be capable of sampling the steam passing it, the ratio of its effective area to that of the steam-pipe having been determined by preliminary experiment. Such an instrument might be called a wet and dry bulb platinum thermometer, the dry bulb being the standard

(Mr. C. M. Clark.)
resistance by which the current passing through the strip was measured. With this contrivance he hoped to be able to carry out the needful experiments shortly, feeling sufficient confidence to do so from some experiments in which he had been engaged six years ago, wherein a calorimeter was heated from below the temperature of a surrounding jacket to above it, with the object of attempting thereby to eliminate losses from radiation. Unless the air space between the calorimeter and the jacket was dry, this method was unsuccessful; for so long as the calorimeter was below the temperature of the jacket any moisture in the air space was condensed on the walls of the calorimeter, and before the calorimeter could rise above the temperature of the jacket that moisture had to be evaporated. The presence of moisture could always be detected by the temperature of the calorimeter remaining stationary for some time at the temperature of the jacket, before any further rise in temperature took place.

For practical use any calorimeter should be capable of being easily connected to any steam-pipe. It was not always possible to make a coupling to a steam-pipe, unless either a T piece could be put in, or a suitable boss had been cast on the pipe. The simplest way to open a steam-pipe was at a flange joint; and the electrical calorimeter readily lent itself to doing so; for by making the electrical connections of thin sheet copper, and placing them between two asbestos rings, good electrical insulation and a good joint were secured at the same time. Of all the apparatus described in the paper, that most likely to be used in workshop practice was the steam-jacketed separator, as it was the most simple, and the results given by its use appeared to be concordant. Through the kindness of the author he had been enabled to use one of those instruments, and had found that the results were fairly concordant. Its weak point was that it was not always easy to find a place for attaching it to the steam-pipe. It might be inserted by removing one of the drains; but if these had been properly designed, it was not always convenient to dispense with one. Moreover the condenser as at present designed seemed to him to be faulty, because the expansion of the water due to heating could not be

neglected, and a temperature correction of the scale was of little good, since it was difficult to keep the water thoroughly mixed and to read the water level on the scale at the same time and also to note the temperature. Nor was it desirable to make the weight of water condensed dependent on the difference of the weighings of two quantities, each of them approximately half a hundredweight. A small surface-condenser would probably meet this difficulty. Furthermore, if steam was passed into the separator too rapidly, the pressure under which the water was collected in the separator might be high. Then when the valve was closed before taking a reading, condensation took place in the jacket of the separator, the pressure would be diminished, and the water in the separator would boil away. This would be an especially exasperating performance when, as the separator had to be close to the steam-pipe, the readings were taken under conditions of personal inconvenience. One of the most valuable aids to good measurement of any sort, and one too apt to be overlooked, was the personal comfort of the observer.

Dr. JOHN HOPKINSON, Member of Council, considered the economy of dry steam compared with wet steam to be due to the fact that, if wet steam was introduced into the cylinder, the expansion and accompanying evaporation of the moisture at once cooled the cylinder, and consequently in the next stroke there was a considerably greater initial condensation of the steam when freshly admitted to the cylinder.

With regard to the way in which separators worked, it seemed to him that a good separator did not work so much by allowing an ample quiet space for the water to settle out of the steam, as by providing sharp corners for the steam to pass round, in order that the water by its greater momentum might there separate itself from the steam. The action was just like that of the dust separators used in grain warehouses, where the dust-laden air was passed through a number of orifices, at each of which its direction was abruptly changed, and the dust particles being heavier than the air were carried forward in a straight line by their momentum, and were thus thrown out of the air current. So it was in the steam separators; the steam was made

(Dr. John Hopkinson.)

to pass rapidly round corners, and the water in suspension was thrown out of the current and deposited in a receptacle.

Professor UNWIN said it was a broad issue that had been raised by Mr. Longridge (page 50) in urging the desirability of abandoning small apparatus and proceeding at once to determine the total amount of moisture in the total amount of steam. It was quite possible that this was what might come to be done*; and he should therefore have been glad if Mr. Longridge had brought forward some results obtained in this way, or had indicated what grounds he had for supposing that observations on so large a scale could be carried out with anything like the accuracy with which they could be made in the small apparatus. Unfortunately it seemed rather contrary to the whole tendency of all scientific work to suppose that observations of this kind could be carried out on a large scale as accurately as they could on a small scale. Engineers were generally content to determine the calorific value of their fuel by analysing a sample of a few grams only, and the amount of heat wasted in their chimney by analysing a few cubic inches of the escaping gases; and he did not see why they should not be content to analyse their steam also by treating a few pounds or cubic feet of it.

The experiments referred to by Mr. Donkin (page 53) as having been carried out by M. Henry had been made on the total-heat method of Hirn, and there was nothing original about them; they were merely examples of carefully carrying out the total-heat method, which M. Henry had thought to be the best, and his judgment must of course have proper weight attached to it. For his own part however he was inclined to think it was not the best method, even of those that were known.

The calorimeter arranged by Gehre (page 54) was simply a later form of that suggested by Cummins, as described in the paper (page 40), differing from it only in the mechanical detail of a couple of valves to cut off the sample of steam suddenly. Those valves he

* In the Mulhouse trials in 1856 one of the methods tried was to take all the steam used through a spare boiler acting as a large separator. Corrections were made for radiation. But the results were untrustworthy.

considered it was impossible to construct in a satisfactory way. The principle of the two calorimeters was identical; the mechanical details of the Gehre seemed not to be practicable.

The ancient and respectable salt test seemed to Professor Capper (page 61) to have been treated in the paper with somewhat scant courtesy. For this test he had sufficient respect to make him wish he could trust it more. The unfavourable opinion he had been led to form of the salt test depended mainly on the fact that, in a series of salt tests with the same boiler, conducted by the same accomplished operator, Professor Schröter of Munich, with no change in the conditions, the values obtained for the dryness of the steam varied enormously; and he accordingly distrusted the salt test a good deal. More ample details as to the salt methods were given in the original Report (British Association Report 1894, pages 404–9).

As to getting an accurate sample of the steam flowing along a steam-pipe, some of the remarks made in the discussion seemed to have proceeded on the assumption that there was quite a distinct flow of dry steam and of wet steam along the steam-pipe; and that by some means or other it was necessary to mix up the steam in the pipe, before a fair sample could be got. This however he thought was not a difficulty at all. With the steam eddying along the steam-pipe at a general velocity of 100 feet per second, he did not conceive that there could be any great lack of homogeneousness in the mixture; and a mistake he thought would be made in putting anything solid into the pipe which would disturb the proper homogeneousness of the steam, and would collect by adherence more water and less steam. For his own part, at any rate until a degree of refinement was reached which had not yet been attained, he believed it did not matter whether the steam was taken from the middle of the pipe or from the side; all that was wanted was to get the steam out of the pipe without attracting into the collecting pipe more water than there ought to be with the sample of steam which was being got. The arrangement often used, as had been conclusively shown by Professor Jacobus, collected too much water with the steam; it disturbed the current, and collected out of the steam more water than it ought to take in proportion to the steam.

(Professor Unwin.)

The use of superheated steam, whereby the need of testing the dryness of steam would be obviated, had been advocated by Mr. Cawley (page 61). No one believed more thoroughly than himself that steam considerably superheated would be used in many places and on many occasions in the future; but it would not be adopted all at once; and even if it were, boilers would still have to be tested as to whether they gave dry or wet steam, in order to determine their efficiency, apart from what might be done with the steam afterwards when it went into the superheater: so that he was afraid the problem of the dryness of steam would still have to be dealt with, even when superheated steam was being used in engines.

The difficulty and inaccuracy attending the use of the thermometer had been mentioned by Capt. Sankey (page 65). In the Carpenter separating calorimeter however, Fig. 1, Plate 1, which for many purposes he thought the best, no thermometers were wanted; it was not necessary to know the temperature of the steam at all. In the wire-drawing calorimeter, Fig. 5, Plate 4, the wetness was determined from the difference of the readings of two thermometers placed in nearly similar conditions; and therefore thermometer errors partly compensated each other.* Whatever error there was

* The effect of an error of the mercurial thermometer in determining the dryness of steam by observations with the wire-drawing calorimeter is easily calculated. Suppose the observations gave $t_1=300^\circ$ and $t_2=240^\circ$ as the temperatures before and after wire-drawing, and that the temperature corresponding with the pressure in the second chamber was $t_3=214^\circ$; then, writing the formula for the dryness fraction in its most exact form, $x = \frac{h_3 - h_1 + L_3 + 0\cdot48\,(t_2 - t_3)}{L_1}$. The values of the liquid heat h and heat of vaporisation L being taken from Peabody's tables, we get $x = 0\cdot9848$ or $1\cdot52$ per cent. of moisture in the steam. Now suppose the mercurial thermometers gave the steam temperatures 2° too low. Re-calculating we get $x=0\cdot9851$ or $1\cdot49$ per cent. of moisture in the steam. There are three causes tending to make the mercurial-thermometer temperatures differ from the true temperatures, and acting on both thermometers in the same direction and nearly to the same extent:—the difference of mercurial and air-thermometer temperatures; the difference of temperature of bulb and stem; and the difference of temperature on the steam and air side of the iron thermometer-tube. By proper use of the

in one thermometer, there was likely to be pretty closely the same in the other: so that the difference of the readings was for this particular purpose more accurate than might be supposed from the possible error in the use of thermometers in taking the temperature of steam. Although certainly there were errors in using ordinary thermometers in conditions like those in the Barrus calorimeter, yet those errors could be evaded to a great extent by calibrating the thermometers in position by the use of Regnault's tables, as had been suggested by Professor Jacobus. To do this it was necessary to have sufficiently accurate means of ascertaining steam pressures; and Professor Jacobus had such means at the Stevens Institute.

As to the value 0·48 taken for the specific heat of superheated steam (page 63), here again for the particular object in view it did not make much difference what was the exact value of the specific heat of superheated steam. A somewhat different value might be taken from that adopted in page 39, without getting any great difference in the dryness fraction there given for the steam. In the most admirable researches carried out by Mr. Macfarlane Gray on the physical constants of steam, numerical values had been determined in a certain way for the specific heat of superheated steam. Those researches were so interesting that they would have a permanent value in the science of steam, even if the actual numerical values should not prove to be precisely true. The values rested on certain ideas about the physical constitution of steam, which he thought were not yet verified in such a way as would justify the introduction of the calculated values into a practical estimate of the dryness of steam. Moreover the means of determining the dryness of steam had not yet been carried to such a pitch of accuracy that great exactness in the value of the specific heat was important. So far as there was any experimental evidence on this point, the constant

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thermometers the error can be made small; and in the criticisms of mercurial thermometers in the discussion the fact seems to have been overlooked that Regnault's and many other researches of equal importance depend on mercurial-thermometer temperatures taken in the same way as those in the Barrus calorimeter.

(Professor Unwin.)

value 0·48 for the specific heat was much better for the present purpose, even if it was somewhat wrong, than the variable value calculated by Mr. Macfarlane Gray. As to whether there was or was not a loss by radiation in the wire-drawing calorimeter, he had endeavoured to speak cautiously in page 39 of the paper, as well as in regard to the accuracy of the usual value 0·48 which he had assumed for the specific heat of steam. All that was necessary in using the wire-drawing calorimeter was that the wetness should be calculated from the two observed temperatures. His own observations showed that, starting with steam of known quality and using 0·48 for the specific heat, the calculated temperature in the second chamber agreed with that observed. Hence if 0·48 was wrong, the errors balanced.

In connecting Mr. Willans' remarkable experiments with the American experiments made with what was called the barrel calorimeter (page 36), he had done so because in both alike the total-heat method had been used; he had gone on to point out that, instead of a barrel such as was used in America, Mr. Willans had used a tank containing nearly three tons of condensing water and condensing one cwt. of steam. Capt. Sankey argued (page 65) for the accuracy of Mr. Willans' results on the ground of their small deviation from the mean value. But his experiments had all been made under closely similar conditions, and the accordance of the results proved little. Under such conditions errors, if present, would be constant errors, and would affect all the results similarly.

There arose one question of rather considerable importance, namely on what scale was it best for practical purposes to carry out such experiments? While Mr. Willans had thought to eliminate a great deal of difficulty by experimenting on a large scale, there appeared to himself to be considerable doubt whether he had not taken a wrong direction in that respect. In some experiments of Joule's it had been shown that by working on a small scale, with only two gallons of condensing water and condensing only a few grams of steam, the total heat of dry steam could be determined with an accuracy quite as great as that with which it had been determined by Mr. Willans with three tons of condensing water for

condensing one cwt. of steam. On a small scale it was possible to be as accurate as on a large scale, as these two sets of experiments showed. No doubt taking one cwt. of steam ensured to a certain extent a better sampling. On the other hand if the experiments were to be carried out on so large a scale, they would almost necessarily be limited to a single experiment. If Hirn's smaller apparatus were used, at least half a dozen experiments might be made in the same time; and the average of half a dozen small experiments would possibly be better than a single big experiment. Moreover although experiments on a large scale diminished some errors, they increased others; and for this reason also he was not sure that Mr. Willans had taken the right direction in experimenting on so large a scale.

A good deal had been said about the difficulty arising from the supposed fact that water was carried along in contact with the sides of the steam-pipe. Although Professor Barr stated that he had also suggested a similar way to that proposed by himself for getting a sample of steam out of the centre of the steam-pipe (page 67), he nevertheless objected that this was of no use, because a great deal of water was carried along the sides of the pipe. In certain American papers a good deal had been said about water on the side of the pipe. For his own part he was inclined to think that this notion was a great bugbear. The first place at which the dryness fraction had to be determined was at the boiler; and there the steam could be taken from a vertical pipe so close to the boiler that there was no chance of any water of any consequence flowing along the sides of the pipe. In a boiler trial therefore the supposed difficulty from water flowing along the pipe was one which need not affect the result at all, if only reasonable care were taken in the choice of the position for the calorimeter. In an engine trial the case was no doubt somewhat different. Before the steam reached the engine, it had flowed through a considerable length of pipe and perhaps through a number of pipes, and had probably received a considerable accession of condensed water, a good deal of which was probably in contact with the pipe. The proper thing to do therefore in an engine trial was

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to put in a large separator, which if it did nothing else would trap all the water flowing in contact with the steam-pipe. Then in addition to the separator a calorimeter was wanted between the separator and the engine, in order to see what the state of the steam was which went to the engine after leaving the separator.

The statement by Captain Sankey (page 65), that Joule's experiments on the determination of the mechanical equivalent of heat had been discovered to be one per cent. in error, was rather misleading. Joule had adopted a wrong correction for reducing mercurial to air-thermometer temperatures. Using the proper correction, Joule's results agreed closely with the most recent determinations.

Mr. Clark's suggestion (page 74) of a new description of calorimeter was interesting; but it was obvious that the indications of such an instrument would be indirect, and it had not been stated how such an instrument could be calibrated, or the value of its indications determined. The difficulty of finding a place for attaching the instrument to the steam-pipe he thought could hardly be regarded as an objection to the Carpenter calorimeter (page 76). If calorimeters were to be used, arrangements for attaching them must be provided, just as for attaching indicators. In most cases a screw plug was all that was necessary. He should be glad to think the determination of the dryness of steam approached such a degree of accuracy that the error of weighing the condenser was an appreciable quantity. He had found no difficulty in determining the amount of steam condensed accurately enough, either by direct weighing of the condenser, or by the use of the attached scale with a correction for expansion. He thought also that Mr. Clark's method of using the instrument must have been peculiar; it was entirely unnecessary to close any valve before taking a reading, and indeed it would be improper to use the instrument in that way.

A final word might perhaps be useful. It was not the wetness fraction of steam, but the dryness fraction, which was of interest to engineers. The heat given to a pound of steam in the boiler, or received from a pound of steam in the engine, was proportional

almost exactly to the dryness fraction. Now in steam containing 2 per cent. of moisture, an error of 20 per cent. in the wetness fraction would correspond to an error of only about one half of one per cent. in the dryness fraction.*

The PRESIDENT said it did not seem very long since it had been necessary to insist upon the fact that boilers used coal, and engines used water. Happily such a necessity had now passed away, and a stage had been reached when a discussion upon the mere determination of the amount of water present in steam had given rise in the first instance to such an excellent paper as Professor Unwin's, and in the second place to so interesting a discussion, and thirdly to so interesting a reply thereto. He had now great pleasure in moving that the cordial thanks of the Institution be presented to Professor Unwin for his paper.

Dr. JOHN RYAN, being unable to come to the meeting, wrote beforehand that doubtless the combination of the Carpenter separator with the Barrus wire-drawing apparatus will give a fairly accurate account of the moisture in the particular sample of steam that is passed through these two instruments, and that the observations thus made will be self-accordant; but it is by no means clear that they can measure even approximately the wetness of the steam as it is continuously delivered to a running engine. The author's remarks (pages 32-3 and 46) on the origin of the moisture indicate the importance of the velocity of the steam and the importance of radiation. The moisture-sustaining power of the steam increases greatly with its velocity, probably as the cube of the velocity; and the moisture present is augmented by every facility for radiation. Most of the ingenious instruments hitherto used

* Since the discussion Professor Peabody has forwarded an interesting paper, "An Experimental Study of the Errors of different types of Calorimeters;" Transactions of the American Society of Mechanical Engineers, vol. xi, page 193. Unfortunately this was not known to the author when writing the paper.

(Dr. John Ryan.)
appear to the writer to manufacture to some extent their own moisture; and apart from this, to receive the steam in a different condition from that in which it actually sweeps into the steam-chest of the engine. While recognising the admirable theoretical merits of these instruments, he should not care to place reliance on any of them as indicators of the actual quality of the steam in the steam-pipe. In support of these criticisms the writer notes that the author found 13·82 per cent. of moisture when the separator was used alone, but only 3·93 per cent. when both instruments were in use together. Presuming the explanation given in page 46 to be in the main accurate, it supports the view that a rate of condensation peculiar to each instrument will obtain in the branch pipes and connections and exposed parts of the instruments themselves. And again, in addition to unknown condensation in the connecting pipes, the Carpenter separator and other instruments with gauge-glasses inevitably involve condensation of the steam in the gauge-glasses themselves, and consequent error in the determination of moisture. Apart from this, the graduations of the gauge-glasses would be misleading, because the water in the gauge-glasses must be colder than the water inside the instrument, and adjustment of temperature will be slow.

In the forthcoming trials of a steam engine recently inaugurated in the University College, Bristol, he purposes ascertaining the wetness of the steam by two methods; either of these he thinks likely to afford a fairer sample of the actual steam as delivered to the engine, and a more reliable mode of determining its condition. Both modes involve simple weighings, which can be done with the greatest ease and accuracy; they may be classed as density methods, and either of them ought to enable the moisture to be determined within 1-20th of one per cent.

The first plan is to replace a section of the steam-pipe near the engine by a double-branched pipe, in one branch of which the steam is entrapped on its way to the engine. This branch is an alternative route, and is steam-jacketed. In order to take a sample of steam, this alternative route is opened, and the valve in the ordinary branch is closed. When a fair sample is obtained, the valves in the branch are

shut, while steam is turned on by the ordinary route. The imprisoned steam is allowed to escape gradually and at leisure, condensing in a suitable vessel attached to a drain-pipe at the bottom of the branch. This vessel is eventually removed and weighed; while the uncondensed vapour is absorbed by a chemical absorbent, phosphorous pentoxide or calcium chloride or quicklime or strong sulphuric acid; in the case of the first, metaphosphoric acid is a highly stable product. Thus the total weight of steam and moisture is ascertained. The volume of the steam space can be accurately measured by filling it when hot with water, and weighing the water. Thus the density of the steam may be determined, and its wetness deduced from the excess of the observed density above that of dry saturated steam of the same temperature. Leakage through the valves can be obviated by an extra valve at each end, forming a lock, out of which the then useless steam can be discharged into the atmosphere while the sample steam is condensing.

The second plan differs from the first in detail only, and is open to the objection that it does not ensure so fair a sample of steam. It involves a small dome or casting on the top of the steam-pipe near the steam-chest. The casting encloses a small cylinder open at the top, within which the sample of steam is to be entrapped. The top of the cylinder is closed by a piston, which is pressed down by the outer steam while the contents are condensing. The danger of leakage past this piston is met by allowing the sample steam to escape very slowly through the smallest possible opening of a regulating cock in a drain-pipe at the bottom of the cylinder. As it escapes, the steam pressure in the outer dome will gradually press the piston down in the cylinder, and maintain the internal pressure: so that no sensible difference of pressure will exist on the two sides of the piston, to cause leakage. A counter-weight acts against friction. The process can be repeated indefinitely, and any number of cylinders full of steam condensed consecutively, so that the product can be weighed in the aggregate. In order to facilitate the lifting of the piston, steam is admitted to the bottom of the cylinder through a valve-opening. When the piston reaches the top, it uncovers large ports, through which the steam fills the cylinder,

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and through which it is allowed to blow at the commencement of the test. As in the first plan, there are here only two measurements: the weight of the combined steam and water in the sample, and the volume of the sampling cylinder up to the ports: both of which are easily made, and are susceptible of accurate determination. A chemical absorbent can be used for the residual vapour, but will hardly be needed if the process is repeated many times at each sampling.

In the writer's opinion the American plan ought not to be followed of calling instruments for separating water from steam, or for other measurements not involving the observation of heat quantities, by the familiar title of "calorimeters," which is contrary to scientific usage. The fact that the "barrel calorimeter" was rightly so called (page 36) does not justify the use of the name "Barrus calorimeter."

In the continuous condensing methods where the steam is admitted to an injector through narrow passages at a high velocity, a minute error must be introduced by ignoring the kinetic energy of translation of the steam, which is so much extra heat not strictly belonging to the steam actually condensed, but derived from the boiler. But a more serious error is that made by many of the observers—in the writer's opinion both by Mr. Willans and by the Americans—who have overlooked the fact that the heat given out by steam condensing in the open air is not the same as the total heat involved in the generation of the same steam under pressure in the boiler, the external work being different in the two cases.

Can any salt method of measuring priming water be reliable, where a fresh-water feed is continually disturbing the uniformity of concentration in the boiler?

Professor UNWIN desired to state that the paper would sufficiently show he disagreed with Dr. Ryan's views of the wire-drawing and separating calorimeters; and that he did not care to criticise the purely hypothetical methods which he had sketched out. They seemed to be open to the certainty of errors enormously greater than, for instance, the error due to radiation from 3 inches of gauge-glass, to which he had

referred. Apparently he misunderstood the two observations on the Barrus and Carpenter calorimeters used together and the Carpenter used alone. Instead of invalidating the trustworthiness of the instruments, it was a striking confirmation of their reliability. The steam supplied to these calorimeters was initially practically dry steam. The moisture found in it was wholly due to radiation from the 30 feet of pipe connecting the calorimeters with the boiler. The moisture, as it should do, decreased to about one-third when the velocity along the pipe was about trebled. The 30-foot branch-pipe was of course used only because the instruments themselves were being tested, and there was no interest in testing the steam in the steam pipe. In using the instruments for testing the dryness of steam it was not necessary to use 30 feet of branch pipe.

As to the name calorimeter, all the instruments were in fact used to determine the total heat of a pound of steam, and the term calorimeter was quite appropriate. In stating that a serious error was involved from overlooking the fact that the heat given out by steam condensing in the open air was not the same as the total heat involved in the generation of the same steam under pressure in the boiler, the external work being different in the two cases, Dr. Ryan appeared to have fallen into an elementary fallacy. He must be discussing such conditions of condensation as were involved in Hirn's method; otherwise the remark had no relevance. On examining Joule's experiments, given in the British Association Report, it would be found that condensation under such conditions gave identically the same values as Regnault's determinations.

EXPERIMENTS ON A VERTICAL SINGLE-CYLINDER STEAM-ENGINE, WITH AND WITHOUT STEAM IN THE JACKETS, CONDENSING AND NON-CONDENSING, DOUBLE AND SINGLE-ACTING, AT DIFFERENT EXPANSIONS, WITH SATURATED AND SUPERHEATED STEAM.

BY MR. BRYAN DONKIN, OF LONDON.

Engine.—In 1889 the author erected at the engineering works of Messrs. Bryan Donkin and Co., Bermondsey, a vertical single-cylinder engine specially designed for experimental purposes, having cylinder of 6 inches diameter and 8 inches stroke, with surface-condenser and rope-brake. As shown in Plates 9 and 10 the engine is of ordinary construction, and without novelty. No great economy was expected, and it was desired only to obtain a careful record of facts, by changing one set of conditions at a time. Attention was particularly directed to the effect of raising or lowering the temperature of the cylinder walls, and to the experimental range of the steam temperature in the cylinder. It will be seen that the economic results depend considerably on the cylinder temperature. In several experiments the range of steam temperature was kept constant, and the temperature of the walls varied; in others the temperature of the walls was kept the same, but the steam range varied. The different conditions affecting the economy of steam are also noticeable. This economy is least when working non-jacketed, non-condensing, and double-acting, with cut-off at 1-8th of the stroke, when it is equal to 62 lbs. of steam per I.H.P. per hour; it is better non-jacketed and condensing; again better jacketed and non-condensing; still better jacketed and condensing with cut-off at 1-10th, when it is equal to $24\frac{1}{3}$ lbs. of steam per I.H.P. per hour; and finally the maximum

economy is attained when working with superheated steam, jacketed, condensing, double-acting, and with cut-off at 1-16th of the stroke, the steam consumption being then as low as 21 lbs. per I.H.P. per hour. The speed was about 220 revolutions per minute in almost all cases. More reliable information and better comparisons can be obtained, the author considers, by making a series of experiments on one engine and varying one condition at a time, than by many experiments on different engines.

Objects of Experiments.—One object aimed at was to determine the economic effect of working the engine condensing or non-condensing, double or single-acting, with steam on both sides of the piston or on the top only, keeping the steam pressure and speed constant, while varying the cut-off so as to obtain the best rate of expansion. Arrangements were also made to superheat the steam 10° to 70° Fahr., in order to compare superheated steam in some experiments with saturated steam in others, at the same number of expansions and speed, all other conditions being likewise the same. On the question of speed, tests were made at 220 and at 110 revolutions per minute, the pressure and cut-off being constant. Experiments were also made with steam pressures of 50 and 25 lbs. per square inch above atmosphere, at the same speed and number of expansions, and with and without steam in the different jackets. The barrel jacket was also connected with the surface condenser, in order to determine the effect of a vacuum in the jacket. A test was made with this jacket filled with water, and another when filled with oil kept hot by a series of small gas jets round the outside of the jacket. Some 150 experiments were made in all, extending over a period of about eighteen months. Some of the tests on the effect of steam-jackets have already been published in the Proceedings of this Institution (1892, page 444), and a few have been made use of by Professor Dwelshauvers-Dery in his work "Etude calorimétrique de la machine à vapeur."

Steam and Boiler.—The steam was taken from the factory boiler close by, in which the pressure was generally 60 lbs. per square inch above atmosphere. The maximum pressure selected to work at was 50 lbs. near the valve-chest of the engine, so as to avoid any small

variation of boiler pressure. The steam was found to be practically dry, showing generally about 1-3rd of one per cent. of priming. All the results are worked out, not in fuel consumption, but in lbs. of steam or of feed-water per I.H.P. per hour weighed from the surface condenser, as being the better and more accurate standard. The thermal efficiency, or the heat equivalent to I.H.P. divided by the total heat received by the engine, is also added for each experiment. The amount of steam per I.H.P. per hour always includes all the jacket water, but does not include the steam condensed in the well-clothed steam-pipe.

Description of Engine and Apparatus.—The intended speed was 220 revolutions per minute, equal to 293 feet per minute piston-speed. Two cylinders were used. The first, bolted on the vertical frame, had no steam-jacket; and with it the experiments in series 1 to 8 were made. Afterwards a second cylinder was fixed on the same frame, and used for the other experiments in series 9 to 13. The latter was provided with a special barrel steam-jacket, in which the steam condensed, that is the water running down on the two vertical cylindrical surfaces, was divided into two parts and weighed separately; the water representing the heat going through the cylinder wall ran down the inner jacket wall, and was kept separate from that which was due to external radiation only, and which was uselessly condensed on the outer jacket wall. The top and bottom covers and the steam-chest cover were provided with jackets; and any one, two, or all four of these jackets could be worked with or without 50 lbs. steam pressure in them, by means of direct steam pipes. The water from each was weighed separately. A pressure gauge and an air-cock were fixed on the barrel jacket. The steam pipe was trapped just before the steam-chest, in order as far as possible to prevent any water from going into the cylinder.

Indicator diagrams were taken by a Crosby indicator, the two ends of the cylinder being joined together by a half-inch well-covered pipe about 10 inches long. Diagrams were also taken with two indicators, one attached to the top and the other to the bottom of the cylinder; but with this short well-covered pipe no practical difference

could be detected, whether one or two indicators were used. There were two piston-rods, upper and lower, of the same diameter; so that the top and bottom diagrams could be directly compared. The clearance volumes were nearly the same at top and at bottom, and were determined both by calculation and by filling with water. The surfaces of these spaces were carefully calculated; also the ratio of surface to volume at cut-off. The valves were of the ordinary flat kind, one main valve with one eccentric, and two cut-off valves driven by another eccentric; the expansion valves were variable by hand, and made to cut off between the limits of 1-24th to 3-4ths of the stroke. The index cut-off plate was accurately marked off. The piston, valves, and surface condenser were tested for leakage every two or three days.

The surface condenser consisted of a number of $\frac{3}{4}$-inch tubes, and the total cooling surface was 37 square feet. The condenser was always used to measure the feed-water, whether the test was condensing or non-condensing; in the latter case a small air-cock was opened, allowing air to enter, and causing the vacuum gauge to stand at zero, as if the engine were worked non-condensing. The feed-water from the air-pump was carefully weighed in a six-gallon can placed on a standard weighing machine; and each test was terminated when the weighing machine showed exactly 50 lbs. All tests were made in duplicate, the mean of the two being taken; in some few cases where they disagreed, the experiment was condemned and repeated. The fly-wheel was provided with a dry rope-brake of the usual construction, the rim being turned hollow to contain water for keeping the wheel cool. The air pump, $1\frac{1}{2}$ inch diameter and 12 inches stroke, was at first driven at different speeds, but afterwards was always worked at about one-third the speed of the engine, by means of a rope from the crank-shaft, this speed being found to give the best vacuum. A counter worked off the cross-head gave the number of revolutions of the engine; and a tachometer showed at a glance the approximate speed.

Clearance Volumes and Surfaces.—For the unjacketed cylinder the mean clearance volume of top and bottom was 20·4 cubic inches, with

1·017 square foot of surface. For the jacketed cylinder the clearance volume was 19·65 cubic inches, except for experiments 121 to 134 inclusive, when it was increased to 20·15 inches; the surface in both cases was 1·037 square foot. The internal surfaces from which the condensation during admission was calculated are the mean surfaces exposed during admission up to cut-off. Fig. 3, Plate 11, shows the increasing surfaces touched by the steam during a stroke, up to release.

Temperatures of Walls.—These were taken by the method previously described in the Proceedings 1893, page 480. Small holes were drilled longitudinally to a considerable depth into the cylinder and jacket walls, and were filled with mercury. Into these holes small mercurial thermometers were inserted for obtaining the temperatures. The holes were so placed as to leave the following thicknesses of metal between them and the inside of the cylinder:— 0·06, 0·12, 0·24, 0·35, 0·47, 0·59, 0·71, and 0·83 inch; and 0·12, 0·24, 0·35, 0·47, and 0·59 inch from the inside of the jacket wall.

Temperature Cups.—These were used to hold mercurial thermometers, in order to give the various temperatures. Several of them, about 3-16ths inch internal diameter and 2 inches long, were screwed into the following parts of the engine:—steam-pipe, near the engine; steam-chest; inside the barrel-jacket; exhaust-pipe, near the cylinder; and surface condenser. The difference of temperature between the steam in the steam-pipe and that in the exhaust-pipe near the cylinder gave the range of steam temperature, or the difference in temperature of the steam when entering and leaving the cylinder. The range was also taken from the corresponding maximum and minimum pressures shown by the indicator diagrams. Calculated from these, it was rather less than that shown by the thermometers, as the diagrams could not take account of the drop in steam pressure on entering the cylinder. When working with superheated steam, the range taken by the thermometers includes the superheating.

Programme of each Trial.—A separate log-sheet was used for recording the particulars of each trial. The usual duration of each experiment was about forty minutes, being the time required to

fill twice the 50-lb. can on the weighing machine; the first twenty minutes gave a check upon the second. Indicator diagrams from the top and bottom of the cylinder were taken every five minutes, as were also the steam pressures in the steam-pipe and jacket, the vacuum in the condenser, and the reading of the counter. Temperature of superheated steam, every two minutes. Temperature of air-pump discharge, of cylinder walls, and of cups, every ten minutes. Initial temperature of circulating water, being constant, every ten minutes; but its final temperature every minute. The spring balance on the brake was read every ten minutes. Generally the two halves of each experiment agreed within 2 per cent., or sometimes less; the results given are the average of both. In many cases, working under the same conditions, the times taken to fill the can were exactly the same. A few long experiments were made of about three hours each, which confirmed the results arrived at by the shorter trials. Three assistants were sufficient to take the required observations and diagrams, and the author was present throughout the trials.

Limits of Possible Error.—Every care was taken to minimise errors. The indicator springs were carefully tested, and the diagrams are probably correct within 2 per cent. Non-metallic glazed writing paper was used for the diagrams, as it gives less friction than the metallic paper and the metal point. The weighing machine for feed-water gave results within 2 ozs. in 50 lbs., or 1-4th of one per cent. The temperature errors due to the glass thermometers may amount to 5 per cent., glass being an imperfect conductor of heat. There is little doubt that with a perfect thermometer the range of temperature of the cylinder walls would have been greater, particularly nearest to the internal surfaces. In the non-fluctuating portion of the metallic walls however, the temperatures given will be very near indeed to the truth. In any new experiments some form of electrical thermometer might perhaps be used, and would probably yield better results; but the author does not know of a good one.

Experiments.—These are divided into thirteen series. The first eight series, comprising fifty experiments, were made with the non-

jacketed cylinder, having a single 1-inch wall. The ninth to thirteenth series of thirty-three experiments were with the steam-jacketed cylinder, having a 1-inch cylinder wall cast in one piece with a 5-8ths inch jacket wall, leaving a 7-8ths inch jacket space for steam, air, water, vacuum, or oil. The same cylinder covers were used throughout, but in the non-jacketed cylinder experiments the spaces inside the covers were open to the air. In all the tests, the outer surfaces of the cylinder or jacket, of the covers, and of the steam-chest, were well clothed with about 2 inches of asbestos, etc. The outer surfaces of the asbestos were comparatively cool.

Indicated Horse-power for Engine alone.—Experiments were made with the non-jacketed cylinder, indicating the engine without any load, at different speeds, with the following results. At about 100 revolutions per minute the I.H.P. of the engine, including air-pump, was equal to 0·46; at 150 revolutions 0·77; at 200 revolutions 1·10; and at 250 revolutions 1·33 I.H.P. This gives 1·20 I.H.P. as the power required to drive the engine and air-pump only, without load, at about 220 revolutions per minute. The mechanical efficiency, or ratio of brake to indicated horse-power, is added in each experiment. The above figures when plotted give a very regular curve.

Temperature of Walls Outside at ends of Non-jacketed Cylinder.—These temperatures were taken in order to ascertain whether the two end temperatures were greater, as was thought probable, than the temperature at mid-stroke. It was found that, when working condensing and double-acting and cutting off at 1-8th stroke, the temperature on the outside of the wall was practically the same at one end as at the other, while the middle of the cylinder length was some 17° Fahr. cooler. The two ends are exposed inside to the hotter initial steam, whereas at mid-stroke the pressures are less, which probably accounts for some of the difference in temperature. This difference of the initial and mid-way steam, taken from the indicator diagram, was 64°. When working single-acting, the difference in temperature of the metal is still more marked: with steam in the top of the cylinder, the centre was 28° cooler than the top, and the difference between the top with steam and the bottom without steam

was 37°. Calculated from the diagram of pressures the corresponding difference in steam temperature inside the cylinder was 85°.

Economy obtained by using the different Jackets.—In all the experiments with this engine a gain was found when steam-jackets were used. This gain was generally more, the greater the number of expansions; and was no doubt chiefly due to the temperature of the jacketed cylinder being nearer to the temperature of the entering steam. The following Table 1 gives the results of four experiments: first, without steam in any of the jackets; second, with steam in the two cover-jackets only (horizontal surfaces); third, with steam in the barrel-jacket only (vertical surfaces); fourth, with steam in all the four jackets. The engine was running at 218 revolutions per minute, condensing, with saturated steam, cutting off at 3-16ths stroke, and expanding $3\frac{3}{4}$ times. The weight of steam per I.H.P. per hour gradually decreased from 41·2 to 28·4 lbs. If this be plotted upon a base line of square feet of internal jacketed surface, it will be

TABLE 1.—*Saving due to Jackets.*

Experiment.	Condition of Jackets.	Feed-Water, including jacket-water. Per I.H.P. per hour.	Saving due to Jackets; gain on 41·2 lbs. Per I.H.P. per hour.	Percentage Gain.	Ratio of Jacketed surface to total internal surface of Cylinder.
No.		Lbs.	Lbs.	Per cent.	Per cent.
108	WITHOUT steam in any jackets . .	41·2	—	—	—
112	WITH steam in two cover jackets only .	37·0	4·2	10·2	17·2
117	WITH steam in body jacket only . .	30·1	11·1	26·9	64·9
121	WITH steam in all four jackets . . .	28·4	12·8	31·1	82·1

seen how the economy increases with the number of square feet of hot metal surface. The difference in temperature of the walls with all the jackets and with none was about 40°. The percentages of water from the different jackets in experiment 121 with all the jackets in use were:—barrel jacket, inner wall 32 per cent., outer wall 32 per cent.; top cover 7 per cent.; bottom cover 20 per cent.; valve chest 9 per cent. The total quantity of water from the jackets in this experiment was 2·1 lbs. per I.H.P. per hour, equal to 7·4 per cent. of the total feed.

Water, Vacuum, and Oil in Jacket.—Jacketing the cylinder with hot water increased the steam consumption 12 per cent. as compared with no steam in the jackets. The engine was worked for some time before the trial commenced, so that the water in the jackets became warm. When the jacket was connected with the surface condenser, there was a gain of nearly 8 per cent. due to a vacuum in the body jacket, as compared with no steam in the jackets. With the body jacket filled with mineral oil kept at a temperature of 375°, and with steam in the other jackets, there was about the same economy as with steam in all the jackets. Thus the oil did not give any advantage, although it was kept at a higher temperature than the steam used in the jacket; it appeared to part with its heat very slowly to the cast-iron walls. Therefore there does not seem any advantage with oil jackets; on the other hand there is the cost of heating the oil.

Jackets and Speed.—Comparing two experiments as to the effect of steam jackets at the two different speeds of 218 and 116 revolutions per minute, at the lower speed the gain due to the jackets was rather greater than at the higher, the difference amounting to only 3 per cent. greater gain at the lower speed.

Gain with Jackets; Non-condensing.—Comparing two non-condensing experiments, one with and the other without jackets, all other conditions being the same, the gain due to jacketing was 43 per cent. The great difference in the temperature of the cylinder walls with and without steam in all the jackets is noticeable, amounting to over 40°

Jackets and Dryness-Fraction.—The effect of steam-jacketing on the dryness-fraction of the steam in the cylinder, both at cut-off and at release, is marked. If the steam economy and the dryness-fraction at release are plotted graphically, it will be seen that the two curves agree fairly. Thus the steam consumption increases or decreases with the wetness of the steam; in other words, the drier the steam at release, the greater is the economy, the maximum economy being obtained with practically dry steam at release.

Superheated Steam in Cylinder and Jackets, or in Cylinder only.—When working with steam in the cylinder superheated to nearly 60° there was a gain in economy of 26 per cent. due to all the jackets being supplied with superheated steam as well as the cylinder, in comparison with no jackets in use. This was when the engine was working at 200 revolutions per minute, condensing, and expanding 6·8 times with cut-off at 1-16th of the stroke. The cylinder metal was found to be 50° hotter when the jackets were supplied with superheated steam than without the jackets in use.

Conclusion.—The conclusion to be drawn from these jacket experiments is that, with the same quality and temperature of steam, the hotter the temperature of the cylinder metal, the greater is the economy. With cylinders of the same temperature, the drier and hotter the steam, the greater is the economy. The temperature of the walls touched by the steam is therefore of considerable importance.

Condensation in Cylinder with walls colder than the Steam.—The mean rate of steam condensation during admission, expressed in pounds per hour per square foot of internal cylinder surface, has been plotted in Plates 13 to 19, as also the difference of temperature between the walls and the initial steam; and it will be seen that the curves agree pretty closely. In other words, the nearer the temperature of the walls is to that of the initial steam, the less is the condensation and the greater is the economy.

Condensation of Steam in Cylinder.—The condensation during admission is given in the tables of results for most of the experiments. The following explains, by a numerical example, the method adopted for calculating the weight of steam condensed per hour per square

foot of internal surface exposed during admission. The weight of steam passing through the cylinder per stroke is known for each experiment, as also the weight of steam present in the cylinder per stroke, shown by the indicator diagrams at cut-off. The difference represents the weight of steam condensed in the cylinder per stroke, during the period from admission to cut-off. For calculating the rate of condensation per square foot per hour, the question of time must be taken into account, and for this purpose the velocity of the crank-pin is assumed to be uniform. The piston being in the position when steam is cut-off at 3-16ths of the stroke, the angle passed through by the crank-pin from the opening to the closing of the steam valve can be obtained, and expressed in decimals of a revolution. This figure multiplied by the time occupied by one revolution will give the time for the steam-admission period only. The surface exposed to the steam during admission has next been calculated. This is a variable quantity for the different expansions. Beginning with the surface exposed in the clearance and passages, it increases, and for any particular cut-off is equal to the surface of clearance and passages, plus one side of piston, and part of cylinder and piston-rod. If the total surface exposed be plotted, as shown by the upper full curve in Fig. 3, Plate 11, on a base of the angle passed through by the crank-pin, the mean surface exposed during admission can be found by measuring the mean height of this curve between the opening and closing of the steam valve, as shown by the lower dotted curve. At 3-16ths cut-off the mean surface is 1·095 square foot. The weight of steam condensed being known, and also the time occupied by condensation during admission, and the mean internal surface exposed to the steam during this time, the result can be expressed in pounds of steam condensed per hour per square foot; and this is added for each experiment. The amount of water present at the end of expansion can be calculated in the same way, by taking the total water and steam present at release, and working it out in lbs. per square foot per hour.

Numerical Example for Calculating Condensation.—Experiment 108 non-jacketed, condensing, cut-off at 3-16ths of stroke, revolutions 220 per minute, number of expansions 3·77.

Steam passing through cylinder per stroke . . .	0·010240 lb.
Steam present at cut-off, as shown by indicator diagrams	0·003827 lb.
Condensation during admission per stroke ($62\frac{1}{2}$ per cent.)	0·006413 lb.

Here one revolution takes $60 \div 220 = 0{\cdot}2727$ second. The crank passes through $60\frac{1}{2}$ degrees during the admission period, which therefore occupies $60\frac{1}{2} \div 360 = 0{\cdot}168$ revolution. Time of admission, $0{\cdot}2727 \times 0{\cdot}168 = 0{\cdot}04583$ second. Mean surface exposed during admission up to 3-16ths cut-off, 1·095 square foot. Rate of condensation, 0·006413 lb. in 0·04583 second, or 0·1399 lb. per second; or 504 lbs. per hour, or 460 lbs. per square foot per hour. For experiment 121 jacketed, calculating in the same way as above, the condensation up to cut-off is at the rate of 217 lbs. per square foot per hour, or less than half the foregoing. The difference between the two cases is that in the latter the temperature of the walls was considerably raised.

Experiments with Superheated Steam.—When superheated steam was used in these experiments, the steam pipe conveying the steam to the engine was heated by a row of gas jets immediately under it, and quite near the cylinder. This method was adopted as being convenient, but a great deal of the heat was wasted in radiation. Although rather extravagant in gas, it answered the purpose well. The small portion of heat taken up by the steam has not been allowed for in the above comparisons between saturated and superheated steam. The superheating was in all cases rather small, never exceeding 70°.

Graphic Representation of Condensation.—In Fig. 4, Plate 11, are given the graphic representations of the condensation of steam during one stroke, on a base line of equal times; four curves have been plotted for four different typical experiments, Nos. 108, 44, 121, and 150. These curves show the weight of water in the cylinder at the different portions of the stroke, calculated in the usual way from the weight of feed-water per stroke after cut-off, and compared with

the steam shown by the indicator diagrams, the difference being water. The highest curve OXZ gives the weight of water present when working non-jacketed and with saturated steam; the point X is the maximum on this curve. The next below gives the amount when working non-jacketed and with superheated steam. The third shows less condensation, working with steam-jackets and with saturated steam. The lowest curve gives the minimum rate of condensation, using superheated steam both in the cylinder and in the jackets; this curve is much flatter, the condensation is much less, and the re-evaporation slower. At the zero of surface O, the curves start from zero of condensation; the dotted portions up to the point of cut-off are only assumed.

Thirteen tables of results are appended for the thirteen series, pages 118–139; a summary is added of each series, and some comparisons are made. The ratio of square feet of surface to cubic feet of volume at cut-off differed greatly in the different experiments, according to the number of expansions: at 1-24th cut-off this ratio is a maximum of 64 to 1, and at 3-4ths cut-off it is a minimum of 18 to 1. The author has to express his thanks to Messrs. Golding and Hicks for valuable assistance during this long series of tests.

Table 2 on the following page 103 gives a few typical experiments arranged in order of water consumption per indicated horse-power per hour, all at about 220 revolutions per minute, and with 50 lbs. steam pressure.

Summary of Experiments.—Series 1.—This set of ten experiments was made when working with 50 lbs. pressure of saturated steam, and with the non-jacketed cylinder, condensing and double-acting, at about 220 revolutions per minute. The details are given in the table appended, pages 118–19. The number of expansions only was varied from $5\frac{3}{4}$ to $1\frac{3}{4}$, all other conditions being kept constant. The results are as follows. The I.H.P. increased from $4\frac{1}{4}$ to 9; the mechanical efficiency from 70 to 86 per cent. The consumption of steam per I.H.P. per hour decreased from $43\frac{1}{2}$ lbs. to $35\frac{1}{2}$ lbs., and then increased again; the proportion of steam present at release increased from 57 to 69 per cent., and then decreased. The range of steam

TABLE 2.—*Consumption of Feed-Water per I.H.P. per hour.* *See page* 102.

Revolutions per minute about 220. Steam Pressure 50 lbs. per square inch above atmosphere.

NOT jacketed or Jacketed.	Series.	Experiment.	Single or Double Acting.	Condensing or Non-condensing.	Steam Saturated or Superheated.	Number of Expansions.	Cut-off, fraction of stroke.	Mean Effective Pressure on piston per square inch.	Feed-Water per I.H.P. per hour.	Thermal Efficiency. *
	No.	No.						Lbs.	Lbs.	Per cent.
NOT jacketed.	6	66	Single	Non-condensing	Saturated	$1\frac{3}{4}$	half	11·32	62·03	3 75
	7	69	Single	Non-condensing	Superheated	$1\frac{3}{4}$	half	12·19	50·92	4·48
	3	49	Double	Non-condensing	Saturated	$1\frac{3}{4}$	half	29·39	46·69	5·07
	4	55	Single	Condensing	Saturated	$1\frac{3}{4}$	half	16·36	46·03	5·02
	3	52	Double	Non-condensing	Superheated	$1\frac{3}{4}$	half	29·57	41·76	6 13
	5	60	Single	Condensing	Superheated	$1\frac{3}{4}$	half	16·97	41·33	5·44
	1	32	Double	Condensing	Saturated	$1\frac{3}{4}$	half	37·01	38·30	6·20
	2	35	Double	Condensing	Superheated	$1\frac{3}{4}$	half	36·57	33·67	6·90
Jacketed.	10	137	Double	Condensing	Saturated	$1\frac{3}{4}$	half	43·37	30·70	7·29
	9	121	Double	Condensing	Saturated	$3\frac{3}{4}$	3-16	28·64	28·39	8·14
	11	152	Double	Condensing	Superheated	7	1-16	18·21	20·91	10·8

* Thermal Efficiency = Heat equivalent to I.H.P. ÷ Total Heat received by engine.

temperature was about constant. The temperature of the cylinder walls gradually increased from 233° to 276°, giving a difference of temperature between the walls and the steam of from 65° to 21°, the walls being always colder than the initial steam. With more steam passing through the engine, the walls become hotter. Under these conditions considerable condensation may be expected; but the rate gradually decreased from 515 lbs. per hour per square foot of internal surface at the maximum expansion to 209 lbs. at the minimum. Thus the condensation decreased considerably as the temperature of the walls increased. The thermal efficiency increased from $5\frac{1}{3}$ to $6\frac{1}{2}$ per cent. Thermal gradients are given in Fig. 5, Plate 12, of the temperatures at different depths in the cylinder walls, when cutting off at 1-12th and at half stroke. The following results have been plotted in Figs. 7 to 10, Plate 13: weight of steam passing through the cylinder per hour; weight of steam used per I.H.P. per hour; weight of steam accounted for by indicator diagrams per I.H.P. per hour at release; rate of condensation during admission; and number of degrees the walls were colder than the initial steam. It will be seen that these last two quantities follow each other very closely in the ten experiments. In Figs. 11 and 12 is shown the appearance of the condensation inside a glass cylinder attached to the engine cylinder, when cutting off at 1-12th and at 5-16ths respectively. The ratio of the surface to the volume at 1-12th cut-off was 49 square feet to one cubic foot, and at half stroke it was $21\frac{1}{2}$ square feet to one cubic foot. In experiment 41, with cut-off at 1-4th stroke, a thermometer was inserted in the cylinder cover, being put inside a small pipe which was screwed into the cylinder cover. By the added volume of this small pipe the clearance volume was enlarged, and the number of expansions consequently reduced to 2·97. In experiments 26 and 27, when the thermometer was not in use, the pipe was taken out and the hole in the cylinder cover plugged up, thereby reducing the clearance volume, and increasing the number of expansions to 3·13.

Series 2.—This set of eleven experiments, with the non-jacketed cylinder condensing and double-acting, at about 220 revolutions per

minute, was made with superheated steam of 50 lbs. pressure, the amount of superheat varying from 12° to 68°. The number of expansions only was varied from $7\frac{1}{2}$ to $1\frac{1}{4}$, all other conditions being kept constant. The results are as follows; some of them are plotted in Figs. 13 to 16, Plate 14. The I.H.P. increased from 3·61 to 9·94. The mechanical efficiency increased from 69 to 88 per cent. The weight of steam used per I.H.P. per hour, Fig. 14, decreased from $28\frac{1}{2}$ lbs. to a minimum of 26 lbs., and then increased to a maximum of $39\frac{1}{4}$ lbs. The percentage of steam present at release decreased from about 83 to $71\frac{1}{2}$ per cent. The range of steam temperature in the cylinder was about constant. The temperature of the cylinder walls increased from 248° to 281°, and was colder than the initial steam, the difference varying from 119° to 29°, Fig. 16. The rate of condensation during admission decreased from 331 lbs. to 120 lbs. per hour per square foot of surface exposed, Fig. 15. The thermal efficiency decreased from a maximum of $8\frac{3}{4}$ to a minimum of 6·1 per cent. The walls were found to be hotter with superheated than with saturated steam at the same cut-off. The rate of condensation during admission, and the number of degrees the walls were colder than the steam, follow each other fairly in the eleven experiments, with two exceptions: that is to say, as the difference in temperature between the steam and the walls is less, the rate of condensation is reduced. Comparing the first series using saturated steam with the second using superheated, it will be seen that there is a marked economy due to the use of superheated steam; according to the number of expansions the saving varies from 7 to 40 per cent., although the steam was only slightly superheated.

Series 3.—This set includes six experiments with saturated steam of 50 lbs. pressure, and one experiment with superheated steam at the same pressure; in all seven the engine worked non-jacketed, non-condensing, double-acting, and at about 220 revolutions per minute. The number of expansions only was varied from $4\frac{3}{5}$ to $1\frac{1}{4}$, all the other conditions being kept constant. The results, some of which are plotted in Figs. 17 to 20, Plate 15, are as follows.

The I.H.P. increased from 3 to 8·4. The mechanical efficiency increased from 58 to 85 per cent. The weight of steam per I.H.P. per hour decreased from 62·1 to 44·4 lbs. The proportion of steam present at release increased from 69 to $76\frac{1}{2}$ per cent. The range of steam temperature in the cylinder was about constant. The temperature of the cylinder walls increased from 246° to 282°, and was from 54° to 16° colder than the initial steam. The rate of condensation per hour per square foot during admission showed a marked decrease from 440 to 105 lbs. The thermal efficiency increased from $3\frac{3}{4}$ to 5·4 per cent. The rate of condensation during admission, and the number of degrees the walls were colder than the steam, follow each other closely, decreasing uniformly with the diminishing number of expansions; the later the cut-off, the hotter the walls.

Comparing experiment 45 in series 1 condensing with experiment 46 in series 3 non-condensing, both using saturated steam and having $4\frac{2}{3}$ expansions, the weight of steam per I.H.P. per hour was reduced from 62·1 lbs. non-condensing to 42·9 lbs. condensing, or 31 per cent. less when condensing. The range of steam temperature was 76 per cent. greater when condensing than when non-condensing; yet with this increased range there was still the above economy. Comparing experiment 43 condensing with experiment 47 non-condensing, the economy due to condensing with $3\frac{2}{3}$ expansions was 33 per cent. Comparing respectively experiments 37 and 32 condensing with experiments 48 and 49 non-condensing, the economy due to condensing with $2\frac{1}{2}$ and $1\frac{3}{4}$ expansions was 26 and 18 per cent. respectively. Comparing experiment 35 condensing in series 2 with experiment 52 non-condensing, both using superheated steam, the economy due to condensing with $1\frac{3}{4}$ expansions was 19 per cent.

Series 4 *and* 5.—These include ten experiments, five with saturated and five with superheated steam of 50 lbs. pressure. The expansions only were varied from $4\frac{2}{3}$ to $1\frac{1}{4}$, the other conditions being kept constant. In all ten the engine worked non-jacketed, condensing, single-acting, and at about 220 revolutions per minute.

In the five experiments with saturated steam the results were as follows. The I.H.P. increased from 2 to 4·8. The mechanical efficiency increased from 49 to 75 per cent. The weight of steam per I.H.P. per hour decreased as the expansion decreased, from 56 lbs. to 46 lbs., and then increased a little, Plate 16, Fig. 22. The proportion of steam present at release increased from 45 to 67½ per cent. The range of steam temperature decreased from 153° to 132°. The temperature of the cylinder walls increased from 223° to 276°, and they were from 73° to 22° colder than the initial steam, Fig. 24. The rate of condensation during admission decreased from 576 lbs. to 171 lbs. per hour per square foot, Fig. 23. These last two quantities follow each other closely: that is, as the expansion decreased and more steam passed through the cylinder, so the walls increased in temperature, thus reducing the difference between their temperature and that of the steam, and thereby diminishing condensation.

In the five experiments with superheated steam, as the expansions decreased the I.H.P. increased from 2½ to 4·6, and the mechanical efficiency increased from 68 to 81 per cent. The weight of steam per I.H.P. increased from 38½ to 44¼ lbs. per hour, Plate 16, Fig. 22. The proportion of steam present at release increased from 55 to 73 per cent. The range of steam temperature decreased from 204° to 178°. The temperature of the cylinder walls gradually increased with greater quantities of steam passing through the engine, from 248° to 274°; the walls were from 103° to 72° colder than the entering superheated steam, Fig. 24. The rate of condensation decreased from 432 to 127 lbs. per hour per square foot, Fig. 23. These last two quantities follow each other closely.

Comparing experiment 55 saturated with experiment 60 superheated, both cutting off at half stroke, and at the same speed and pressure, there is 10 per cent. economy in steam used per I.H.P. per hour with superheated steam, and with about the same temperature of walls. The rate of condensation with superheated steam is 35 per cent. less, though with 55° greater range of steam temperature.

Comparing experiment 55 single-acting in series 4 with experiment 32 double-acting in series 1, both with saturated steam cut off at half stroke, and at the same speed and pressure, there is 17 per cent. economy in steam used per I.H.P. per hour when double-acting, and the walls are 10° hotter. The rate of condensation when double-acting is 38 per cent. less, with the same range of steam temperature.

Comparing experiment 60 single-acting in series 5 with experiment 35 double-acting in series 2, both with superheated steam cut off at half stroke, and at the same speed and pressure, there is 18 per cent. economy in steam used per I.H.P. per hour when double-acting, and the walls are 10° hotter. The rate of condensation when double-acting is 31 per cent. less, with 22° less range of steam temperature.

Series 6 *and* 7.—These two series each include four experiments, the sixth with saturated steam of 50 lbs. pressure, and the seventh with superheated steam of the same pressure. The number of expansions only was varied from 3 to $1\frac{1}{4}$, all other conditions remaining the same. In all eight experiments the engine was working non-jacketed, non-condensing, single-acting, with the bottom of the cylinder open to the condenser, and at about 220 revolutions per minute.

In series 6 with saturated steam, the I.H.P. increased from 1·4 to 3·3. The mechanical efficiency increased from 28 to 60 per cent. The weight of steam per I.H.P. per hour decreased from a maximum of $80\frac{3}{4}$ lbs. to a minimum of 60·4 lbs., Plate 16, Fig. 26. The proportion of steam present at release decreased from 63 to 59 per cent., and then increased to 69 per cent. The range of steam temperature in the cylinder varied only a few degrees. The temperature of the walls gradually increased from 246° to 276°, being greater as the quantity of steam passing through the engine increased; they were always from 49° to 22° colder than the entering steam, Fig. 28. The rate of condensation during admission decreased considerably from 311 to 139 lbs. per hour per square

foot, Fig. 27; and followed closely the difference of temperature between the walls and the initial steam.

In the four experiments in series 7 with superheated steam the amount of superheat was 50°. The I.H.P. increased from 1·4 to 3·4. The weight of steam per I.H.P. per hour decreased from 64 to 51 lbs., Plate 16, Fig. 26. The proportion of steam present at release varied a little from about 76 to 77 per cent. The range of steam temperature increased from 118° to 140°. The temperature of the cylinder walls increased from 258° to 278° with the greater quantity of steam passing through the engine. The walls were always much colder than the superheated steam, Fig. 28; and their temperature rose with the greater quantity of superheated steam passing through the cylinder, the rate of condensation during admission being less; the latter decreased from 192 to 103 lbs. per square foot per hour.

Comparing experiment 66 saturated with experiment 69 superheated, both cutting off at half stroke, all other conditions being the same, there was an economy of 18 per cent. due to superheated steam. The walls were 8° hotter with the superheated steam. There was also 30 per cent. less condensation during admission, due to the hotter steam; and this even with 54° greater range of steam temperature.

Comparing experiment 66 non-condensing in series 6 with experiment 55 condensing in series 4, both with saturated steam cut off at half stroke, and at the same speed and pressure, there is 26 per cent. economy in steam used per I.H.P. per hour when condensing. The walls are 3° colder, and the rate of condensation is 58 per cent. greater when condensing, with 51° greater range of steam temperature.

Comparing experiment 69 non-condensing in series 7 with experiment 60 condensing in series 5, both with superheated steam cut off at half stroke, and at the same speed and pressure, there is 19 per cent. economy in steam used per I.H.P. per hour when condensing. The walls are 10° colder, and the rate of condensation is 46 per cent. greater, with 52° greater range of steam temperature.

Series 8.—This set consists of four experiments at about 220 revolutions per minute, two with saturated and two with superheated steam of 50 lbs. pressure, and at two different expansions for each, all other conditions remaining constant. These were made with the engine working non-jacketed, non-condensing, single-acting, and with the bottom of the cylinder open to the atmosphere. With $1\frac{3}{4}$ expansions the steam used per I.H.P. per hour was 46 lbs. saturated and 43·4 lbs. superheated, the amount of superheat being 50°; the economy due to superheating was thus about $5\frac{3}{4}$ per cent. The temperature of the cylinder walls was about the same in each case. The rate of condensation during admission was 10 per cent. less with the superheated steam; the range of steam temperature was 65° greater.

The experiments given in series 6, 7, and 8, afford the means of making a comparison between the results of working non-condensing, single-acting, with steam on the top of the piston only, firstly when the bottom of the cylinder was open to the condenser, and secondly when it was open to the air. Comparing experiment 66 with 73, both with saturated steam, there is an economy of 26 per cent. in steam per I.H.P. per hour when the bottom of the cylinder is open to the atmosphere, compared with when it is open to the condenser. The temperatures of the cylinder walls were about the same, but the rate of condensation during admission was 37 per cent. less when open to the atmosphere. The range of steam temperature was 15 per cent. less when open to the atmosphere; and the dryness-fraction at release showed 9 per cent. more steam present. Comparing two experiments, 69 and 78, both with superheated steam, there is an economy of 15 per cent. in steam per I.H.P. per hour when the bottom of the cylinder is open to the atmosphere, compared with when it is open to the condenser. The rate of condensation during admission was 20 per cent. less when open to the atmosphere; and the range of steam temperature in the cylinder was about the same, as well as the dryness-fraction at release. The conclusions from these experiments seem to be that when the wet internal walls are exposed to the condenser they lose their heat much more rapidly than when exposed to the atmosphere; the engine requires much more steam

per I.H.P.; and there is much more condensation during admission. When using superheated steam, the gain in economy of steam when the bottom of the cylinder is open to the atmosphere is reduced from 26 per cent. with saturated steam to 15 per cent. with superheated, all other conditions being the same.

Series 9.—This was the first series with the jacketed cylinder, and comprises seven experiments; the engine worked condensing and double-acting, with saturated steam of 50 lbs. pressure, making about 220 revolutions per minute, and with the same number of expansions throughout, namely $3\frac{3}{4}$. The only conditions that were varied were the different jackets, Plate 17, Fig. 33:—all in use, or none; barrel only jacketed, or covers only jacketed. In Table 3 are given the areas of cylinder surface jacketed by the several covers, and the ratios which these bear to the total

TABLE 3.—*Jacketed Surface of Cylinder.*

Cylinder Jackets.		Top Cover.	Bottom Cover.	Barrel.	Total.
Internal Jacketed Surface of Cylinder exposed to steam	sq. foot	0·19	0·19	1·43	1·81
Percentage of total 2·203 square feet of Clearance and Cylinder Surface exposed to steam at release	per cent.	8·6	8·6	64·9	82·1

area of 2·203 square feet of clearance and cylinder surface exposed to the steam at release. Comparing all jackets and none, the economy due to all jackets was 31 per cent., the steam consumption being $41\frac{1}{4}$ lbs. per I.H.P. per hour without jackets and 28·4 lbs. with them, Fig. 30. In these two cases there was a great difference in temperature of walls, which were 29° hotter with the jackets on. The condensation per square foot per hour during admission was reduced from 460 lbs. without jackets to 217 lbs. with all jackets, or less than half, Fig. 31. The range of steam temperature

differed very little; here therefore with much hotter walls there was a marked economy, with much less condensation during admission. In regard to the advantage of jacketing the top and bottom covers only, in comparison with no jackets the table shows an economy of 10 per cent. due to jacketing these two covers, and also 19 per cent. less condensation during admission. Comparing two experiments with no jackets and with barrel jacket only, the figures given in the table show 27 per cent. economy due to the barrel being jacketed; the walls also were 28° hotter, and the condensation during admission little more than half. With all jackets 82 per cent. of the surface touched by the steam was jacketed. In Fig. 6, Plate 12, are drawn thermal gradients not only through the cylinder wall but also through the jacket wall, showing a marked difference with steam in the jacket or not. It will be seen that the heat from the steam in the jacket radiates outwards through the jacket wall and inwards through the cylinder wall; but when the jackets are out of use, the heat goes outwards through both walls. The greater the percentage of surface jacketed, the greater is the economy. The rate of condensation during admission is plotted in Fig. 31, Plate 17, and the extent to which the walls were cooler than the initial steam in Fig. 32; and with one exception the lines follow each other, falling with increase of jacketed surface.

Series 10.—In this set of thirteen experiments the engine worked both with and without steam in the jackets, condensing, double-acting, with 50 lbs. saturated steam, and at about 220 revolutions per minute. The only conditions varied were the number of expansions from 6·86 to 1·77, cutting off at from 1–16th to half stroke; and with each expansion an experiment was made, both with and without steam in the jackets. Curves have been plotted in Figs. 34 to 37, Plate 18, on a base of number of expansions, showing the weight of steam passing through the cylinder per hour with and without jackets, the steam consumption, and the rate of condensation during admission, as well as the number of degrees the walls were cooler than the initial steam. Taking the pair of experiments 130 and 136 at 6·86 expansions, the steam consumption per I.H.P. per hour was

45·6 lbs. without jackets and $27\frac{1}{4}$ lbs. with all jackets, or 40 per cent. economy due to jackets at this number of expansions. The cylinder walls were found to be 61° higher in temperature with the jackets in use; and the rate of condensation during admission with the jackets on was only one-third what it was with them off. The range of steam temperature did not differ much. At the minimum number of 1·77 expansions in experiments 142 and 137, only 23 per cent. economy was due to the jackets, and the rate of condensation during admission with the jackets was less than half what it was without them. It will be seen that the gain by jackets varies considerably with the number of expansions, Fig. 35, all other conditions being the same: the greater the number of expansions up to a certain point, the greater is the gain. The most economical number of expansions with all jackets on was about 5, and with no jackets only 3. This shows that if only two experiments are made with any engine, one with jackets and the other without, the two points so obtained somewhere along two curves will not necessarily be the best results for the particular engine; but there will be a best cut-off for the minimum consumption of steam with jackets, and another best cut-off for minimum consumption of steam without jackets. In this series the walls were always colder than the initial steam; but with jackets in use there was much less difference of temperature than with jackets off. From Figs. 36 and 37 it will be seen that, the hotter the walls, the less is the rate of condensation with no steam in the jackets; but the same seems not to have been the case here with steam in the jackets. In Figs. 38 and 39 is shown the appearance of the condensation inside a glass cylinder attached to the engine cylinder, when cutting off at 1-16th, without and with steam in the jackets.

Series 11.—This series contains five experiments with superheated steam, and with expansions varying from 8 to 5; four with the jackets, and one without; in all five the engine worked condensing and double-acting, at about 200 revolutions per minute, and all other conditions were kept constant. Results are plotted in Plate 19. The number of expansions giving the best economy

with jackets was 6·8, with which the steam consumption was 20·9 lbs. per I.H.P. per hour, Fig. 41. The steam was superheated in this case 59°. The rate of condensation during admission was only 123 lbs. per square foot per hour. The experiment without jackets and with the same number of expansions gave 28·4 lbs. of steam per I.H.P. per hour: so that there is a gain of 26 per cent. due to jackets when working with superheated steam both in the cylinder and in the jackets. The walls were 51° hotter with the jackets in use. The condensation with jackets was much less than half of that without, with about the same range of steam temperature in the cylinder. The rate of condensation, Fig. 42, and the amount by which the walls were colder than the initial superheated steam, Fig. 43, do not follow each other as they do in most of the experiments with saturated steam. In Fig. 45 are shown thermal gradients through the cylinder and jacket walls, with and without steam in the jackets. In Fig. 44 is shown the appearance of the condensation inside a glass cylinder connected with the engine cylinder, when cutting off at 1-16th, with steam in the jackets.

Comparing experiment 136 in series 10 with experiment 152 in this series, the former with saturated steam and the latter with superheated, both with jackets on and both at 6·8 expansions, there is an economy of 23 per cent. due to the steam being superheated 59°. With the superheated steam the rate of condensation during admission was about half that with the saturated steam, and the range of temperature in the cylinder about the same.

Series 12.—This contains a record of five experiments, all with the same number of expansions, namely $3\frac{3}{4}$, and all with saturated steam, and the engine working double-acting. The first pair of experiments 122 and 123 were made at half the usual speed, namely at about 116 revolutions per minute, and condensing, one with jackets and the other without, the object being to determine the effect of jackets under the above conditions. The result was an economy of 34 per cent. due to jackets. The walls were 31° hotter with jackets than without. The rate of condensation with jackets

was reduced to less than half of that without. The range of steam temperature did not differ much ; and there was 29 per cent. more steam present at release with the jackets in use.

The next pair of experiments 125 and 126 were made at the full speed of about 220 revolutions, the engine working double-acting but non-condensing, so as to determine the effect of jackets with the same expansion of $3\frac{3}{4}$ times. The result was an economy of 43 per cent. due to jackets. The walls were 44° hotter with the jackets. The rate of condensation during admission was only about one-third with jackets of what it was without, and with the same range of steam temperature in the cylinder. From these two pairs of experiments it may be inferred that the jackets have a greater economic effect when the engine is working non-condensing than when condensing.

The last experiment 128 of this series was made without jackets, and with saturated steam of the low pressure of only 10 lbs., instead of 50 lbs. ; the engine worked condensing, double-acting, and with $3\frac{3}{4}$ expansions. Comparing this with experiment 108 in series 9, in which the steam pressure was 50 lbs. with the same cut-off and without jackets, there is 26 per cent. economy due to the higher pressure, and the walls were 60° hotter. The rate of condensation during admission with the lower pressure was about half what it was with the higher. The range of steam temperature was 28° less with the lower pressure.

Experiments 108 and 125 show that when working without jackets at $3\frac{3}{4}$ expansions there is 34 per cent. economy due to condensing as compared with non-condensing. Comparing experiments 121 (series 9) and 126, with all jackets in use, there is an economy of 20 per cent. due to condensing as compared with non-condensing. Thus the gain in economy due to condensing when no jackets are in use is more than half as much again as when all jackets are in use.

Comparing experiment 108 at full speed with 123 at half speed, both without jackets, there is an economy of 11 per cent. due to the greater speed. Comparing experiment 121 at full speed with 122 at half speed, both with all jackets in use, there is an economy

of 7 per cent. due to the greater speed. Thus, whether all jackets are in use or none, the gain in economy due to doubling the speed is from 7 to 11 per cent.

Series 13.—In this set of three experiments the engine was working jacketed, condensing, double-acting, and with the same number of $3\frac{3}{4}$ expansions, and at the same speed of nearly 220 revolutions per minute; the only condition varied was the media in the jackets—hot water, hot oil, and vacuum, in the barrel jacket. Comparing experiments 124 in this series and 108 in series 9, 12 per cent. more steam is used with hot water in all the jackets than with air in all the jackets. Comparing experiments 121 (series 9) and 156, about the same economy results whether working with steam or with hot oil in the barrel jacket. Comparing experiments 144 and 108, there is an economy of 8 per cent. with vacuum in the barrel jacket, instead of air. Comparing experiments 144 and 121, 34 per cent. more steam was consumed with vacuum in the barrel jacket than with steam in it; the walls were 18° cooler, and the rate of condensation during admission was nearly doubled.

TABULATED RESULTS OF SERIES 1–13.

SERIES 1.—*Ten Experiments. Non-jacketed, Condensing, Double-acting.*

Expansion varied from $5\frac{3}{4}$ to $1\frac{3}{4}$ times. Saturated Steam, 50 lbs. per square inch above atmosphere.

Revolutions about 220 per minute. Other conditions constant.

Number of Experiment.	Duration of Experiment.	Expansions corresponding with Cut-off. * *See explanation in page 104.*	Steam near Steam-chest. Temperature corresponding with absolute Pressure per square inch.	Steam in Condenser. Temperature corresponding with absolute Pressure per square inch.	Barometric Pressure per square inch.	Revolutions per minute.	Indicated Horse-power.	Brake Horse-power.	Mechanical Efficiency. Percentage.	Steam used per hour. Per Ind. H.P.	Steam used per hour. Per Brake H.P.	Condensation per hour per square foot of surface exposed up to cut-off.
No.	Mins.	Cut-off. Exp.	Lbs. Fahr.	Lbs. Fahr.	Lbs.	Revs.	I.H.P.	B.H.P.	P. c.	Lbs.	Lbs.	Lbs.
53	$51\frac{1}{4}$	1-12th =5·77	66 = 299°	2·0 = 126°	14·87	228	4·22	2·97	70	43·58	62·25	515
45	46	1-8th =4·67	65 = 298°	2·2 = 130°	14·68	226	4·73	3·63	77	42·90	55·70	447
40	$27\frac{3}{4}$	3-16ths =3·63	63 = 296°	1·4 = 113°	14·74	221	5·64	4·70	84	40·64	48·37	383
43	42	3-16ths =3·63	65 = 298°	2·4 = 133°	14·79	223	5·67	4·73	83	40·17	48·39	375
26	$49\frac{1}{4}$	*1-4th =3·13	62 = 295°	1·8 = 122°	14·55	212	6·37	5·22	82	38·64	47·12	—
27	$23\frac{1}{4}$	*1-4th =3·13	65 = 298°	1·8 = 122°	14·55	218	6·60	5·45	83	38·90	46·87	—
41	$37\frac{1}{4}$	*1-4th =2·97	64 = 297°	1·6 = 118°	14·73	224	6·80	5·81	85	37·35	43·93	321
37	$45\frac{1}{2}$	5-16ths =2·54	62 = 295°	2·0 = 126°	14·83	229	7·58	5·92	78	35·50	45·51	264
31	$64\frac{1}{2}$	3-8ths =2·18	62 = 295°	1·7 = 120°	14·92	215	7·73	6·34	82	36·39	44·37	240
32	$34\frac{1}{2}$	half =1·72	64 = 297°	2·9 = 140°	14·95	224	9·14	7·82	86	38·30	44·53	209

SERIES 1 (*continued from opposite page*).

Number of Experiment.	Absolute Pressure per square inch from indicator diagrams.		Percentage of Steam present in cylinder.		Weight of Steam passing through cylinder per hour.	Temperature Range.		Temperature of Cylinder Walls.		Thermal Efficiency. Percentage.	Walls colder than Initial Steam. Innermost hole.	Exposed Surface per cubic foot of Volume at cut-off.	Mean Effective Pressure per square inch.
	Max.	Min.	At Cut-off.	At Release.		In cylinder from maximum initial to minimum exhaust.	As taken by thermometers in steam and exhaust pipes.	Innermost hole.	Average of eight holes.				
No.	Lbs.	Lbs.	Per cent.	Per cent.	Lbs.	Fahr.	Fahr.	Fahr.	Fahr.	P. c.	Fahr.	Sq. Feet.	Lbs.
53	58·8	4·5	29·8	57·1	184	135°	155°	233°	240°	5·30	65°	49·1	16·84
45	60·1	5·9	33·9	59·1	203	123°	153°	242°	245°	5·39	56°	41·7	18·99
40	58·7	5·7	38·5	63·6	229	123°	157°	254°	253°	5·70	42°	34·5	23·20
43	58·2	6·0	39·3	62·7	228	120°	148°	251°	252°	5·76	46°	34·5	23·05
26	56·9	4·4	43·2	64·0	246	132°	140°	257°	254°	5·97	38°	30·1	27·29
27	59·5	4·8	43·7	63·2	257	131°	152°	268°	261°	5·87	30°	30·1	27·51
41	61·3	5·7	45·7	65·6	254	126°	153°	265°	262°	6·20	32°	30·1	27·52
37	60·6	5·3	52·0	68·9	269	128°	145°	264°	262°	6·62	31°	26·9	30·01
31	59·6	4·7	53·0	66·6	281	132°	146°	266°	264°	6·38	28°	24·7	32·60
32	61·2	5·9	60·4	68·4	350	124°	137°	276°	272°	6·20	21°	21·5	37·01

SERIES 2.—*Eleven Experiments. Non-jacketed, Condensing, Double-acting.*

Expansion varied from $7\frac{1}{2}$ to $1\frac{1}{4}$ times. Superheated Steam, 50 lbs. per square inch above atmosphere.

Revolutions about 220 per minute. Other conditions constant.

Number of Experiment.	Expansions corresponding with Cut-off.	Steam near Steam-chest. Temperature of Saturated Steam corresponding with absolute Pressure per square inch.	Steam in Condenser. Temperature corresponding with absolute Pressure per square inch.	Revolutions per minute.	Indicated Horse-power.	Brake Horse-power.	Mechanical Efficiency. Percentage.	Steam used per hour. Per Ind. H.P.	Steam used per hour. Per Brake H.P.	Condensation per hour per square foot of surface exposed up to cut-off.
No.	Cut-off. Exp.	Lbs. Fahr.	Lbs. Fahr.	Revs.	I.H.P.	B.H.P.	P. c.	Lbs.	Lbs.	Lbs.
79	1-24th = 7·54	63 = 296°	1·9 = 124°	222	3·61	2·63	73	28·57	39·13	—
80	1-24th = 7·54	63 = 296°	1·6 = 118°	220	3·60	2·48	69	27·81	40·30	331
81	1-12th = 5·77	63 = 296°	1·4 = 113°	215	4·41	3·41	77	26·93	34·97	—
87	1-12th = 5·77	64 = 297°	1·6 = 118°	227	4·82	3·62	75	25·81	34·41	247
34	1-8th = 4·67	62 = 295°	1·0 = 102°	223	5·17	3·79	73	28·45	38·97	255
44	3-16ths = 3·63	69 = 302°	2·4 = 133°	215	6·30	5·46	86	31·24	36·32	274
36	1-4th = 2·97	61 = 294°	1·3 = 110°	229	6·95	5·60	81	31·20	38·51	233
84	5-16ths = 2·51	64 = 297°	1·8 = 122°	224	7·46	6·49	87	32·87	37·78	—
33	3-8ths = 2·18	64 = 297°	1·6 = 118°	220	8·59	6·87	80	31·95	39·93	—
35	half = 1·72	61 = 294°	2·0 = 126°	222	8·93	7·38	83	33·67	40·56	150
89	3-4ths = 1·21	65 = 298°	4·0 = 153°	218	9·94	8·80	88	39·22	41·56	120

SERIES 2 (*continued from opposite page*).

Number of Experiment.	Percentage of Steam present in cylinder. At Cut-off.	Percentage of Steam present in cylinder. At Release.	Weight of Steam passing through cylinder per hour.	Temperature Range as taken by thermometers in steam and exhaust pipes.	Temperature of Cylinder Walls. Innermost hole.	Temperature of Cylinder Walls. Average of eight holes.	Temperature of Superheated Steam in pipe.	Amount of Superheat.	Thermal Efficiency. Percentage.	Walls colder than Initial Steam. Innermost hole.	Exposed Surface per cubic foot of Volume at cut-off.	Mean Effective Pressure per square inch.
No.	Per cent.	Per cent.	Lbs.	Fahr.	Fahr.	Fahr.	Fahr.	Fahr.	P. c.	Fahr.	Sq. Feet.	Lbs.
79	37·8	82·9	103	167°	248°	248°	347°	52°	7·89	100°	61·8	14·76
80	37·6	85·9	100	170°	250°	250°	349°	53°	8·06	99°	61·8	14·82
81	47·6	81·8	119	172°	257°	254°	348°	52°	8·74	91°	49·1	18·60
87	50·1	88·8	124	176°	256°	256°	348°	51°	8·71	92°	49·1	19·29
34	47·9	77·7	147	217°	244°	249°	363°	68°	7·83	119°	41·7	20·98
44	48·7	71·5	197	198°	264°	265°	347°	45°	7·29	83°	34·5	26·53
36	53·9	72·1	217	206°	265°	261°	346°	52°	7·23	81°	30·1	27·53
84	54·0	71·9	245	165°	269°	266°	313°	16°	6·82	44°	26·9	30·20
33	60·4	74·3	274	186°	275°	271°	336°	39°	7·14	61°	24·7	35·41
35	66·5	75·9	301	170°	277°	276°	326°	31°	6·90	49°	21·5	36·57
89	69·7	73·9	390	144°	281°	280°	310°	12°	6·11	29°	18·1	41·30

SERIES 3.—*Seven Experiments, six with Saturated and one with Superheated Steam. Non-jacketed, Non-condensing, Double-acting.*

Expansions varied from $4\frac{2}{3}$ *to* $1\frac{1}{4}$ *times. Steam pressure* 50 *lbs. per square inch above atmosphere. Revolutions about* 220 *per minute. Other conditions constant.*

Number of Experiment.	Expansions corresponding with Cut-off.	Steam near Steam-chest. Temperature of Saturated Steam corresponding with absolute Pressure per square inch.	Steam in Condenser. Temperature corresponding with absolute Pressure per square inch.	Revolutions per minute.	Indicated Horse-power.	Brake Horse-power.	Mechanical Efficiency. Percentage.	Steam used per hour. Per Ind. H.P.	Steam used per hour. Per Brake HP.	Condensation per hour per square foot of surface exposed up to cut-off.
No.	Cut-off. Exp.	Lbs. Fahr.	Lbs. Fahr.	Revs.	I.H.P.	B.H.P.	P. c.	Lbs.	Lbs.	Lbs.
46	1-8th = 4·67	67 = 300°	14·7 = 212°	225	2·95	1·73	58	62·15	107·10	440
47	3-16ths = 3·63	62 = 295°	14·8 = 212°	218	3·23	2·10	65	60·00	92·30	332
48	5-16ths = 2·51	66 = 299°	14·8 = 212°	223	4·96	2·86	78	48·10	61·67	248
49	half = 1·72	65 = 298°	14·9 = 213°	221	7·17	6·12	85	46·69	54·92	195
50	5-8ths = 1·42	63 = 296°	15·0 = 213°	210	7·17	6·18	86	46·10	53·60	135
51	3-4ths = 1·21	65 = 298°	15·0 = 213°	222	8·41	7·18	85	44·37	52·19	105
			Superheated Steam.							
52	half = 1·72	63 = 296°	14·9 = 213°	215	7·02	5·98	85	41·76	49·12	142

SERIES 3 (*continued from opposite page*).

Number of Experiment.	Percentage of Steam present in cylinder. At Cut-off.	Percentage of Steam present in cylinder. At Release.	Weight of Steam passing through cylinder per hour.	Temperature Range as taken by thermometers in steam and exhaust pipes.	Temperature of Cylinder Walls. Innermost hole.	Temperature of Cylinder Walls. Average of eight holes.	Temperature of Superheated Steam in pipe.	Amount of Superheat.	Thermal Efficiency. Percentage.	Walls colder than Initial Steam. Innermost hole.	Exposed Surface per cubic foot of Volume at cut-off.	Mean Effective Pressure per square inch.
No.	Per cent.	Per cent.	Lbs.	Fahr.	Fahr.	Fahr.	Fahr.	Fahr.	P. c.	Fahr.	Sq. Feet.	Lbs.
46	34·2	73·8	183	87°	246°	248°	Saturated Steam.	Saturated Steam.	3·78	54°	41·7	11·89
47	37·0	69·0	194	79°	249°	251°			3·92	45°	34·5	13·46
48	49·0	69·4	239	84°	267°	268°			4·90	31°	26·9	20·17
49	60·5	72·6	335	85°	277°	276°			5·07	21°	21·5	29·39
50	66·6	73·7	331	81°	278°	276°			5·16	17°	19·5	30·97
51	72·4	76·5	373	84°	282°	280°			5·39	16°	18·1	34·41
Superheated Steam.												
52	67·2	78·1	293	123°	277°	277°	334°	39°	6·13	57°	21·5	29·57

SERIES 4 *and* 5.—*Ten Experiments. Non-jacketed, Condensing, Single-acting.*
Expansion varied from $4\frac{2}{3}$ *to* $1\frac{1}{4}$ *times. Steam pressure 50 lbs. per square inch above atmosphere.*
Revolutions about 220 per minute. Other conditions constant.

Number of Experiment.	Expansions corresponding with Cut-off.		Steam near Steam-chest. Temperature of Saturated Steam corresponding with absolute Pressure per square inch.		Steam in Condenser. Temperature corresponding with absolute Pressure per square inch.		Revolutions per minute.	Indicated Horse-power.	Brake Horse-power.	Mechanical Efficiency. Percentage.	Steam used per hour. Per Ind. H.P.	Steam used per hour. Per Brake H.P.	Condensation per hour per square foot of surface exposed up to cut-off.
No.	Cut-off.	Exp.	Lbs.	Fahr.	Lbs.	Fahr.	Revs.	I.H.P.	B.H.P.	P. c.	Lbs.	Lbs.	Lbs.
					SERIES 4.—*Saturated Steam.*								
56	1-8th	= 4·67	63	= 296°	3·3	= 145°	230	1·98	0·97	49	55·90	114·10	576
57	3-16ths	= 3·63	65	= 298°	2·5	= 135°	229	2·56	1·66	65	50·54	77·75	514
54	5-16ths	= 2·51	64	= 297°	3·1	= 143°	224	3·00	1·88	62	49·14	79·25	379
55	half	= 1·72	65	= 298°	3·5	= 148°	230	4·14	3·01	73	46·03	63·05	336
58	3-4ths	= 1·21	65	= 298°	3·4	= 146°	227	4·80	3·59	75	47·67	63·55	171
					SERIES 5.—*Superheated Steam.*								
63	1-8th	= 4·67	64	= 297°	2·5	= 135°	227	2·50	1·69	68	38·50	56·61	432
62	3-16ths	= 3·63	66	= 299°	2·1	= 128°	224	2·75	1·90	69	41·45	60·06	398
61	5-16ths	= 2·51	64	= 297°	1·5	= 116°	222	3·20	2·68	84	41·00	48·80	290
60	half	= 1·72	66	= 299°	2·6	= 136°	226	4·22	3·37	80	41·33	51·66	218
59	3-4ths	= 1·21	64	= 297°	2·9	= 140°	225	4·58	3·71	81	44·21	54·58	127

SERIES 4 *and* 5 (*continued from opposite page*).

Number of Experiment.	Percentage of Steam present in cylinder. At Cut-off.	Percentage of Steam present in cylinder. At Release.	Weight of Steam passing through cylinder per hour.	Temperature Range as taken by thermometers in steam and exhaust pipes.	Temperature of Cylinder Walls. Innermost hole.	Temperature of Cylinder Walls. Average of eight holes.	Temperature of Superheated Steam in pipe.	Amount of Superheat.	Thermal Efficiency. Percentage.	Walls colder than Initial Steam. Innermost hole.	Exposed Surface per cubic foot of Volume at cut-off.	Mean Effective Pressure per square inch.
No.	Per cent.	Per cent.	Lbs.	Fahr.	Fahr.	Fahr.	Fahr.	Fahr.	P. c.	Fahr.	Sq. Feet.	Lbs.
SERIES 4.—*Saturated Steam.*												
56	28·4	45·1	111	143°	223°	225°	Saturated steam.	Saturated steam.	4·07	73°	41·7	7·81
57	32·8	47·9	129	153°	238°	242°			4·65	60°	34·5	10·12
54	41·8	51·4	148	143°	250°	253°			4·68	47°	26·9	12·16
55	54·7	59·0	191	137°	266°	269°			5·02	32°	21·5	16·36
58	64·7	67·5	229	132°	276°	276°			4·88	22°	18·1	19·19
SERIES 5.—*Superheated Steam.*												
63	38·2	59·7	96	190°	248°	248°	351°	54°	5·95	103°	41·7	9·96
62	41·1	55·0	114	204°	255°	250°	349°	50°	5·53	94°	34·5	11·16
61	49·8	62·2	131	196°	261°	261°	347°	51°	5·60	86°	26·9	13·04
60	60·3	66·0	174	192°	267°	267°	349°	50°	5·44	82°	21·5	16·97
59	70·3	73·3	202	178°	274°	273°	346°	50°	5·22	72°	18·1	18·45

SERIES 6 *and* 7.—*Eight Experiments. Non-jacketed, Non-condensing, Single-acting.*

Expansion varied from 3 *to* $1\frac{1}{4}$ *times. Steam pressure* 50 *lbs. per square inch above atmosphere.*

Revolutions about 220 *per minute. Other conditions constant.*

Number of Experiment.	Expansions corresponding with Cut-off.		Steam near Steam-chest. Temperature of Saturated Steam corresponding with absolute Pressure per square inch.		Revolutions per minute.	Indicated Horse-power.	Brake Horse-power.	Mechanical Efficiency. Percentage.	Steam used per hour. Per Ind. H.P.	Steam used per hour. Per Brake H.P.	Condensation per hour per square foot of surface exposed up to cut-off.
No.	Cut-off.	Exp.	Lbs.	Fahr.	Revs.	I.H.P.	B.H.P.	Per cent.	Lbs.	Lbs.	Lbs.
					SERIES 6.—*Saturated Steam.*						
64	1-4th	=2·97	62	= 295°	224	1·39	0·39	28	80·72	288·3	311
65	5-16ths	=2·51	64	= 297°	214	1·75	0·63	36	74·55	207·1	312
66	half	=1·72	66	= 299°	218	2·71	1·58	58	62·03	106·9	213
67	3-4ths	=1·21	65	= 298°	217	3·34	2·00	60	60·39	100·6	139
					SERIES 7.—*Superheated Steam.*						
71	1-4th	=2·97	65	= 298°	224	1·43	0·24	17	64·00	376·5	192
70	5-16ths	=2·51	66	= 299°	222	1·91	0·71	37	56·18	151·8	195
69	half	=1·72	67	= 300°	223	3·00	1·71	57	50·92	89·3	149
68	3-4ths	=1·21	65	= 298°	220	3·40	2·14	63	53·59	85·1	103

SERIES 6 and 7 *(continued from opposite page)*.

Number of Experiment.	Percentage of Steam present in cylinder. At Cut-off.	Percentage of Steam present in cylinder. At Release.	Weight of Steam passing through cylinder per hour.	Temperature Range as taken by thermometers in steam and exhaust pipes.	Temperature of Cylinder Walls. Innermost hole.	Temperature of Cylinder Walls. Average of eight holes.	Temperature of Superheated Steam in pipe.	Amount of Superheat.	Thermal Efficiency. Percentage.	Walls colder than Initial Steam. Innermost hole.	Exposed Surface per cubic foot of Volume at cut-off.	Mean Effective Pressure per square inch.
No.	Per cent.	Per cent.	Lbs.	Fahr.	Fahr.	Fahr.	Fahr.	Fahr.	Per cent.	Fahr.	Sq. Feet.	Lbs.
						SERIES 6.—*Saturated Steam.*						
64	45·1	63·2	112	83°	246°	246°	Saturated steam.	Saturated steam.	2·87	49°	30·1	5·63
65	45·8	59·6	130	87°	254°	255°			3·12	42°	26·9	7·41
66	59·8	65·6	168	86°	269°	270°			3·75	29°	21·5	11·32
67	67·5	69·1	202	85°	276°	277°			3·87	22°	18·1	13·97
						SERIES 7.—*Superheated Steam.*						
71	58·4	77·4	91	118°	258°	258°	348°	50°	3·55	91°	30·1	5·77
70	58·9	76·3	107	129°	266°	266°	349°	50°	4·03	83°	26·9	7·82
69	69·1	76·2	153	140°	277°	276°	350°	50°	4·48	73°	21·5	12·19
68	74·5	77·1	182	136°	278°	278°	317°	48°	4·26	69°	18·1	14·04

SERIES 8.—*Four Experiments, two with Saturated and two with Superheated Steam.*

Non-jacketed, Non-condensing, Single-acting.

Expansions varied from 3 to $1\frac{3}{4}$ times. Steam pressure 50 lbs. per square inch above atmosphere.

Bottom of cylinder open to atmosphere. Revolutions about 220 per minute. Other conditions constant.

Number of Experiment.	Expansions corresponding with Cut-off.	Steam near Steam-chest. Temperature of Saturated Steam corresponding with absolute Pressure per square inch.	Revolutions per minute.	Indicated Horse-power.	Brake Horse-power.	Mechanical Efficiency. Percentage.	Steam used per hour. Per Ind. H.P.	Steam used per hour. Per Brake H.P.	Condensation per hour per square foot of surface exposed up to cut-off.
No.	Cut-off. Exp.	Lbs. Fahr.	Revs.	I.H.P.	B.H.P.	Per cent.	Lbs.	Lbs.	Lbs.
77	1-4th = 2·97	65 = 298°	219	1·80	0·43	24	50·86	213	181
73	half = 1·72	65 = 298°	210	3·12	1·61	51	46·05	89·4	133
			Superheated Steam.						
72	1-4th = 2·97	65 = 298°	225	1·86	0·26	14	43·53	312	131
78	half = 1·72	67 = 300°	220	3·20	1·75	55	43·43	79·3	119

SERIES 8 (*continued from opposite page*).

Number of Experiment.	Percentage of Steam present in cylinder. At Cut-off.	Percentage of Steam present in cylinder. At Release.	Weight of Steam passing through cylinder per hour.	Temperature Range as taken by thermometers in steam and exhaust pipes.	Temperature of Cylinder Walls. Innermost hole.	Temperature of Cylinder Walls. Average of eight holes.	Temperature of Superheated Steam in pipe.	Amount of Superheat.	Thermal Efficiency. Percentage.	Walls colder than Initial Steam. Innermost hole.	Exposed Surface per cubic foot of Volume at cut-off.	Mean Effective Pressure per square inch.
No.	Per cent.	Per cent.	Lbs.	Fahr.	Fahr.	Fahr.	Fahr.	Fahr.	P. c.	Fahr.	Sq. Feet.	Lbs.
77	57·5	81·4	91	72°	248°	248°	Saturated		4·56	50°	30·1	7·45
73	68·8	75·3	144	71°	271°	272°	steam.		5·06	27°	21·5	13·51
						Superheated Steam.						
72	65·3	87·0	81	117°	256°	256°	317°	50°	5·21	91°	30·1	7·51
78	71·1	79·8	139	136°	273°	274°	349°	50°	5·21	76°	21·5	13·17

SERIES 9.—*Seven Experiments. Jacketed, Condensing, Double-acting.*

Cut-off at 3–16ths = $3\frac{3}{4}$ expansions. Saturated Steam, 50 lbs. per square inch above atmosphere.

Revolutions about 220 per minute. Varied number of Jackets in use. Other conditions constant.

Number of Experiment.	Jackets in use.	Steam near Steam-chest. Temperature corresponding with absolute Pressure per square inch.	Steam in Jackets. Temperature corresponding with absolute Pressure per square inch.	Steam in Condenser. Temperature corresponding with absolute Pressure. per square inch.	Revolutions per minute.	Indicated Horse-power.	Brake Horse-power.	Mechanical Efficiency. Percentage.	Steam used per hour. Per Ind. H.P.	Steam used per hour. Per Brake H.P.	Condensation per hour per square foot of surface exposed up to cut-off.
No.	Jackets.	Lbs. Fahr.	Lbs. Fahr.	Lbs. Fahr.	Revs.	I.H.P.	B.H.P.	P. c.	Lbs.	Lbs.	Lbs.
108	None	61 = 297°	.. ..	2·4 = 133°	220	6·56	5·68	87	41·23	47·38	460
121	All	65 = 298°	67 = 300°	0·9 = 99°	216	6·83	5·95	87	28·39	32·63	217
117	Barrel only	65 = 298°	67 = 300°	1·0 = 102°	217	6·82	5·71	81	30·13	35·86	216
116	Top Cover only	65 = 298°	71 = 301	1·3 = 110°	218	6·50	5·57	87	40·16	46·16	410
115	Bottom Cover only	65 = 298°	69 = 302°	1·5 = 116°	221	6·72	5·56	83	36·92	41·48	398
112	Top and Bottom Covers only	64 = 297°	70 = 303°	1·3 = 110°	221	6·57	—	—	37·01	—	372
109	Steam-chest Cover only	65 = 298°	67 = 300°	1·5 = 116°	217	6·71	5·53	82	39·12	47·70	436

SERIES 9 (*continued from opposite page*).

Number of Experiment.	Jackets in use.	Percentage of Steam present in cylinder. At Cut-off.	Percentage of Steam present in cylinder. At Release.	Weight of Steam passing through per hour. Cylinder.	Weight of Steam passing through per hour. Jackets.	Weight of Steam passing through per hour. Total.	Jacket Water. Weight per I.H.P. per hour.	Jacket Water. Percentage of Feed-water.	Temperature Range as taken by thermometers in steam and exhaust pipes.	Temperature of Cylinder Walls. Innermost hole.	Temperature of Cylinder Walls. Average of eight holes.	Thermal Efficiency. Percentage.	Walls colder than Initial Steam. Innermost hole.	Mean Effective Pressure per square inch.
No.	Jackets.	P. c.	P. c.	Lbs.	Lbs.	Lbs.	Lbs.	P. c.	Fahr.	Fahr.	Fahr.	P. c.	Fahr.	Lbs.
108	None	37·4	60·4	270·3	0	270·3	..	..	146°	255°	260°	5·76	42°	27·04
121	All	55·4	86·3	179·4	14·4	193·8	2·11	7·4	151°	284°	290°	8·14	14°	28·61
117	Barrel only	53·2	80·6	193·9	11·6	205·5	1·70	5·6	154°	283°	290°	7·62	15°	28·57
116	Top Cover only	37·0	62·1	257·3	3·7	261·0	0·58	1·4	160°	255°	257°	5·72	43°	26·99
115	Bottom Cover only	39·8	66·9	243·6	4·7	248·3	0·70	1·9	—	253°	254°	6·24	44°	27·65
112	Top and Bottom Covers only	42·2	63·0	236·6	6·7	243·3	1·02	2 7	156°	250°	256°	6·25	47°	26·60
109	Steam-chest Cover only	38·5	66·1	261·0	1·4	262·4	0·21	0·5	157°	262°	263°	5·78	36°	28·04

Exposed Surface per cubic foot of Volume at cut-off, 35·5 square feet.

SERIES 10.—*Thirteen Experiments. Jacketed, Condensing, Double-acting.*

Expansions varied from $6\frac{7}{8}$ *to* $1\frac{3}{4}$ *times. Saturated Steam, 50 lbs. per square inch above atmosphere.*

Revolutions about 220 per minute. All Jackets in use, and None. Other conditions constant.

Number of Experiment.	Jackets in use.	Expansions corresponding with Cut-off.		Steam near Steam-chest. Temperature corresponding with absolute Pressure per square inch.		Steam in Jackets. Temperature corresponding with absolute Pressure per square inch.		Steam in Condenser. Temperature corresponding with absolute Pressure per square inch.		Revolutions per minute.	Indicated Horse-power.	Steam used per hour per Ind. H.P.	Condensation per hour per square foot of surface exposed up to cut-off.
No.	Jackets.	Cut-off.	Exp.	Lbs.	Fahr.	Lbs.	Fahr.	Lbs.	Fahr.	Revs.	I.H.P.	Lbs.	Lbs.
130	None	1-16th	= 6·86	64	= 297°	..	..	1·2	= 108°	219	4·06	45·60	635
136	All	1-16th	= 6·86	65	= 298°	70	= 303°	1·1	= 105°	222	4·36	27·25	228
138	None	1-12th	= 6·01	64	= 297°	..	..	1·6	= 118°	222	4·48	41·60	579
131	All	1-12th	= 6·01	64	= 297°	64	= 297°	1·0	= 102°	216	5·26	27·81	270
141	All	1-12th	= 6·01	64	= 297°	68	= 301°	1·5	= 116°	221	5·09	25·57	230
139	All	1-10th	= 5·11	64	= 297°	64	= 297°	1·0	= 102°	216	5·40	24·30	165
131	None	1-8th	= 4·87	64	= 297°	..	..	1·7	= 120°	214	5·46	40·98	504
133	All	1-8th	= 4·87	64	= 297°	69	= 302°	0·9	= 99°	216	5·75	25·17	185
140	All	1-8th	= 4·87	64	= 297°	68	= 301°	1·0	= 102°	218	5·96	25·38	182
143	None	5-16ths	= 2·60	65	= 298°	..	..	3·4	= 146°	214	7·77	38·68	331
135	All	5-16ths	= 2·60	63	= 296°	65	= 298°	1·7	= 120°	219	8·27	28·87	151
142	None	half	= 1·77	64	= 297°	..	..	2·7	= 137°	224	9·61	39·91	255
137	All	half	= 1·77	66	= 299°	67	= 300°	2·1	= 128°	205	9·81	30·70	111

SERIES 10 (*continued from opposite page*).

Number of Experiment.	Jackets in use.	Percentage of Steam present in cylinder. At Cut-off.	Percentage of Steam present in cylinder. At Release.	Weight of Steam passing through per hour. Cylinder.	Weight of Steam passing through per hour. Jackets.	Weight of Steam passing through per hour. Total.	Jacket Water. Weight per I.H.P. per hour.	Jacket Water. Percentage of Feed-water.	Temperature Range as taken by thermometers in steam and exhaust pipes.	Temperature of Cylinder Walls. Innermost hole.	Temperature of Cylinder Walls. Average of eight holes.	Thermal Efficiency. Percentage.	Walls colder than Initial Steam. Innermost hole.	Exposed Surface per cubic foot of Volume at cut-off.	Mean Effective Pressure per square inch.
No.	Jackets.	P. c.	P. c.	Lbs.	Lbs.	Lbs.	Lbs.	P. c.	Fahr.	Fahr.	Fahr.	P. c.	Fahr.	Sq. Feet.	Lbs.
130	None	24·0	55·9	185·4	0	185·4	..	..	159°	236°	232°	5·07	60°	56·0	16·87
136	All	53·5	100·5	108·8	10·1	118·9	2·32	8·49	173°	297°	298°	8·46	0°	56·8	19·62
138	None	27·4	60·0	199·8	0	199·8	..	..	158°	240°	237°	5·20	57°	51·0	18·30
134	All	48·9	88·1	132·8	13·6	146·4	2·57	9·29	168°	281°	285°	8·36	15°	50·3	22·10
141	All	51·6	90·7	119·3	11·0	130·3	2·15	8·44	140°	291°	295°	9·06	3°	51·0	20·90
139	All	60·7	98·7	121·1	10·0	131·1	1·85	7·63	167°	287°	288°	9·51	10°	44·7	22·64
131	None	32·4	59·7	223·8	0	223·8	..	..	162°	246°	246°	5·68	51°	42·6	23·18
133	All	58·8	90·8	131·5	10·3	144·8	1·79	7·11	154°	287°	292°	9·15	9°	42·6	24·17
140	All	59·5	95·0	134·7	16·7	151·4	2·79	11·03	156°	284°	285°	9·18	13°	43·1	24·82
143	None	46·1	65·9	300·6	0	300·6	..	..	154°	272°	270°	6·11	26°	27·5	32·89
135	All	66·1	82·2	222·7	16·2	238·9	1·96	6·78	150°	281°	290°	8·18	15°	27·5	31·27
142	None	55·2	65·9	383·8	0	383·8	..	..	140°	275°	272°	5·82	21°	21·9	38·97
137	All	73·8	85·2	286·7	14·5	301·2	1·48	4·81	113°	284°	288°	7·29	15°	21·9	43·37

SERIES 11.—*Five Experiments, four with All Jackets in use, and one with None.*

Condensing, Double-acting. Superheated Steam, 50 lbs. per square inch above atmosphere.

Expansions varied from 8 to $5\frac{1}{8}$ times. Revolutions about 200 per minute. Other conditions constant.

Number of Experiment.	Expansions corresponding with Cut-off.	Steam near Steam-chest. Temperature of Saturated Steam corresponding with absolute Pressure per square inch.	Steam in Jackets. Temperature corresponding with absolute Pressure per square inch.	Steam in Condenser. Temperature corresponding with absolute Pressure per square inch.	Revolutions per minute.	Indicated Horse-power.	Brake Horse-power.	Mechanical Efficiency. Percentage.	Steam used per hour. Per Ind. H.P.	Steam used per hour. Per Brake H.P.	Condensation per hour per square foot of surface exposed up to cut-off.
No.	Cut-off. Exp.	Lbs. Fahr.	Lbs. Fahr.	Lbs. Fahr.	Revs.	I.H.P.	B.H.P.	P. c.	Lbs.	Lbs.	Lbs.
153	1-24th = 7·95	65 = 298°	73 = 306°	1·2 = 108°	200	3·73	2·72	73	21·89	29·98	–
152	1-16th = 6·86	65 = 298°	71 = 304°	1·2 = 108°	198	3·98	2·92	73	20·91	28·64	123
151	1-12th = 6·04	64 = 297°	67 = 300°	1·0 = 102°	200	4·59	3·52	77	21·36	27·73	125
150	1-10th = 5·11	63 = 296°	69 = 302°	0·8 = 96°	222	5·32	3·79	71	21·66	30·50	123
			No Jackets in use.								
154	1-16th = 6·86	64 = 297°	.. ..	1·4 = 113°	197	4·15	3·1	76	28·38	37·34	323

SERIES 11 (*continued from opposite page*).

Number of Experiment.	Percentage of Steam present in cylinder.* At Cut-off.	Percentage of Steam present in cylinder.* At Release.	Weight of Steam passing through per hour. Cylinder.	Weight of Steam passing through per hour. Jackets.	Weight of Steam passing through per hour. Total.	Jacket Water. Weight per I.H.P. per hour.	Jacket Water. Percentage of Feed-water.	Temperature Range as taken by thermometers in steam and exhaust pipes.	Temperature of Cylinder Walls. Innermost hole.	Temperature of Cylinder Walls. Average of eight holes.	Temperature of Superheated Steam in pipe.	Amount of Superheat.	Thermal Efficiency. Percentage.	Walls colder than Initial Steam. Innermost hole.	Exposed Surface per cubic foot of Volume at cut-off.
No.	P. c.	P. c.	Lbs.	Lbs.	Lbs.	Lbs.	P. c.	Fahr.	Fahr.	Fahr.	Fahr.	Fahr.	P. c.	Fahr.	Sq. Feet.
153	..	108·1	75·9	5·7	81·6	1·53	6·98	154°	300°	300°	340°	42°	10·38	40°	64·6
152	65·0	107·0	78·5	4·6	83·1	1·17	5·50	180°	304°	304°	356°	59°	10·80	52°	56·8
151	66·4	102·2	93·2	4·9	98·1	1·08	4·99	162°	298°	298°	338°	41°	10·62	40°	51·0
150	67·4	99·4	109·5	5·7	115·2	1·09	4·90	152°	296°	296°	314°	19°	10·55	18°	44·7
							No Jackets in use.								
154	39·1	87·1	117·7	0	117·7	..	..	178°	253°	255°	331°	34°	8·00	78°	56·8

* Density of Superheated steam assumed equal to that of Saturated steam at same pressure.

SERIES 12.—*Five Experiments. Jacketed and Non-jacketed, Condensing and Non-condensing, Double-acting. Cut-off at 3–16ths = $3\frac{3}{4}$ expansions. Saturated Steam at different Pressures. Full Speed and Half Speed. Other conditions constant.*

Number of Experiment.	Jackets in use.	Steam near Steam-chest. Temperature corresponding with absolute Pressure per square inch.	Steam in Jackets. Temperature corresponding with absolute Pressure per square inch.	Steam in Condenser. Temperature corresponding with absolute Pressure per square inch.	Revolutions per minute.	Indicated Horse-power.	Steam used per hour. Per Ind. H.P.	Steam used per hour. Per Brake H.P.	Condensation per hour per square foot of surface exposed up to cut-off.
No.	Jackets.	Lbs. Fahr.	Lbs. Fahr.	Lbs. Fahr.	Revs.	I.H.P.	Lbs.	Lbs.	Lbs.
				Half Speed and Condensing.					
123	None	64 = 297°		2·0 = 126°	117	3·92	46·25	55·05	351
122	All	65 = 298°	66 = 299°	1·6 = 118°	115	3·72	30·43	32·71	135
				Full Speed and Non-condensing.					
125	None	65 = 298°		14·9 = 213°	221	3·80	62·61	–	422
126	All	65 = 298°	68 = 301°	14·9 = 213°	212	4·19	35·69	–	133
				Full Speed, Lower Pressure, and Condensing.					
128	None	25 = 240°	.. ..	1·7 = 120°	220	2·14	55·95	–	234

SERIES 12 (*continued from opposite page*).

Number of Experiment.	Jackets in use.	Percentage of Steam present in cylinder. At Cut-off.	Percentage of Steam present in cylinder. At Release.	Weight of Steam passing through per hour. Cylinder.	Weight of Steam passing through per hour. Jackets.	Weight of Steam passing through per hour. Total.	Jacket Water. Weight per I.H.P. per hour.	Jacket Water. Percentage of Feed-water.	Temperature Range as taken by thermometers in steam and exhaust pipes.	Temperature of Cylinder Walls. Innermost hole.	Temperature of Cylinder Walls. Average of eight holes.	Thermal Efficiency. Percentage.	Walls colder than Initial Steam. Innermost hole.	Mean Effective Pressure per square inch.
No.	Jackets.	P. c.	P. c.	Lbs.	Lbs.	Lbs.	Lbs.	P. c.	Fahr.	Fahr.	Fahr.	P. c.	Fahr.	Lbs.
Half Speed and Condensing.														
123	None	28·7	55·9	181·1	0	181·1	..	..	152°	260°	262°	4·95	37°	30·41
122	All	52·1	85·4	104·1	9·0	113·1	2·43	7·96	139°	291°	295°	7·54	7°	30·75
Full Speed and Non-condensing.														
125	None	34·7	68·2	237·9	0	237·9	..	..	84°	252°	250°	3·73	45°	15·61
126	All	64·8	95·2	138·9	10·7	149·6	2·56	7·15	85°	296°	297°	6.55	2°	17·91
Full Speed, Lower Pressure, and Condensing.														
128	None	28·1	56·2	119·8	0	119·8	..	..	118°	195°	192°	4·11	45°	8·81

Exposed Surface per cubic foot of Volume at cut-off, 35·2 square feet.

SERIES 13.—*Three Experiments. Jacketed, Condensing, Double-acting.*

Cut-off at 3–16ths = $3\frac{3}{4}$ expansions. Saturated Steam, 50 lbs. per square inch above atmosphere.

Different Media in Jackets. Revolutions about 220 per minute. Other conditions constant.

Number of Experiment.	Media in Jackets.	Steam near Steam-chest. Temperature corresponding with absolute Pressure per square inch.	Media in Jackets. Temperature corresponding with absolute Pressure per square inch.	Steam in Condenser. Temperature corresponding with absolute Pressure per square inch.	Revolutions per minute.	Indicated Horse-power.	Brake Horse-power.	Mechanical Efficiency. Percentage.	Steam used per hour. Per Ind. H.P.	Steam used per hour. Per Brake H.P.	Condensation per hour per square foot of surface exposed up to cut-off.
No.		Lbs. Fahr.	Lbs. Fahr.	Lbs. Fahr.	Revs.	I.H.P.	B.H.P.	P. c.	Lbs.	Lbs.	Lbs.
124	W	65 = 298°	Water = 250°	1·8 = 122°	218	6·32	—	—	46·27	—	542
156	O S	65 = 298°	Oil = 375°	1·5 = 116°	215	6·68	5·57	83	28·86	34·76	237
144	V A	65 = 298°	2·3 = 131°	2·3 = 131°	213	6·35	5·44	86	38·01	44·19	397

W = hot Water (250° Fahr.) in all jackets.

O S = hot Oil (375° Fahr.) in barrel jacket; Steam in bottom cover and valve-chest cover.

V A = Vacuum (131° Fahr.) in barrel jacket; Air in other three jackets.

SERIES 13 (*continued from opposite page*).

Number of Experiment.	Media in Jackets.	Percentage of Steam present in cylinder. At Cut-off.	Percentage of Steam present in cylinder. At Release.	Weight of Steam passing through per hour. Cylinder.	Weight of Steam passing through per hour. Jackets.	Weight of Steam passing through per hour. Total.	Jacket Water. Weight per I.H.P. per hour.	Jacket Water. Percentage of Feed-water.	Temperature Range as taken by thermometers in steam and exhaust pipes.	Temperature of Cylinder Walls. Innermost hole.	Temperature of Cylinder Walls. Average of eight holes.	Thermal Efficiency. Percentage.	Walls colder than Initial Steam. Innermost hole.	Mean Effective Pressure per square inch.
No.		P. c.	P. c.	Lbs.	Lbs.	Lbs.	Lb.	P. c.	Fahr.	Fahr.	Fahr.	P. c.	Fahr.	Lbs.
124	W	31·7	55·4	292·4	0	292·4	..	..	156°	250°	249°	5·04	48°	26·3
156	O S	53·2	83·0	187·6	5·2	192·8	0·99	2·70	145°	298°	298°	8·07	0°	28·2
144	V A	39·4	67·3	241·5	0	241·5	..	..	—	266°	264°	6·10	32°	27·0

W = hot Water (250° Fahr.) in all jackets.

O S = hot Oil (375° Fahr.) in barrel jacket; Steam in bottom cover and valve-chest cover.

V A = Vacuum (131° Fahr.) in barrel jacket; Air in other three jackets.

Exposed Surface per cubic foot of Volume at cut-off, 35·5 square feet.

MEMOIRS.

William Stanway Booth was born at Strangeways, Manchester, on 14th November 1853. After leaving school he went first into an architect's office, and afterwards obtained a situation in the works of Messrs. Ormerod, Grierson and Co., St. George's Iron Works, Hulme. Beginning in the pattern shop, he was soon advanced to the drawing office; and after remaining there thirteen years he was sent to represent the firm in London, where he stayed two years. He was then recalled to the works in Manchester to take charge of the drawing office, and to be joint manager of the business. He next went for a short time as manager to Messrs. H. B. Barlow and Co., Cornbrook Heald Works, Manchester, leaving them for the Lilleshall Iron Works, Wellington, Shropshire, where he stayed two years. There in conjunction with Mr. Muncaster he invented a safety-valve, and a device for the balancing of slide-valves. In 1886 he was appointed engineer to Messrs. Vivian and Sons, Hafod Works, Swansea, having the superintendence of the engineering work connected with the various departments of that extensive firm. In 1892 he became chief engineer to Messrs. John Jameson and Son, at their Bow Street Distillery, Dublin, where he carried out successfully several works for enlarging and developing their premises. His death took place from typhoid fever at Colwyn Bay, North Wales, on 6th December 1894, at the age of forty-one. He became a Member of this Institution in 1890, having been elected a Graduate in 1883.

Lindsay Burnet was born in Glasgow on 5th November 1855, being the second son of Mr. John Burnet, the father of the architectural profession in Glasgow. He served his apprenticeship as a mechanical engineer partly with Messrs. Barclay, Curle, and Co., and partly with Messrs. T. Wingate and Co., Whiteinch, Glasgow. On its completion he went to sea for a short time, in order to get

some further insight into his profession. He afterwards entered the office of Messrs. Bruce and Batho, civil engineers, Westminster. While in London he became an engineering student in University College, under Professor Alexander B. W. Kennedy, with whom the relations of professor and student were soon exchanged for those of a warm personal friendship which lasted for life. In 1883 he commenced business in Glasgow on his own account, devoting himself more particularly to the construction of steam boilers, for which purpose he built the Moore Park Boiler Works at Govan. In 1887 he was joined as a partner by Mr. Sinclair Couper, and the works were thenceforward carried on as the firm of Lindsay Burnet and Co. Besides devoting himself especially to the design and manufacture of steam boilers, he latterly paid much attention to the combustion of coal and other fuels, and to the analysis of these, and of the waste products of combustion, to the methods of dealing with different qualities of water, to smoke abatement, and also to the best means of firing and of burning fuel. In connection with all these matters his work was carried out in the true spirit and with the genuine enthusiasm of a scientific investigator, and his knowledge was both wide and deep. He was moreover always ready, with great frankness although with equal modesty, to place his knowledge and experience at the service of any one who wished to profit by it. As an arbiter his services were much sought in cases of dispute. His enthusiasm for his work, his keen desire to be accurate in everything, his transparent honesty and genuineness of character and his warm-hearted nature made him many friends, who admired him the more for the courageous manner in which he continued his ordinary duties for many months after he had received warnings that the end might come at any time. For some time past he had been in poor health, and at the end of 1894 he caught a chill, which was followed by an attack of influenza, and his death took place on 14th March 1895, at the age of thirty-nine. He became a Graduate of this Institution in 1879, and a Member in 1893; and was an Associate Member of the Institution of Civil Engineers, a Member of the Institution of Naval Architects, and a Member of Council of the Institution of Engineers and Shipbuilders in Scotland.

Frederick Carley Coxhead was born at Greenwich on 24th May 1828. Developing at an early age considerable mechanical ability, he was apprenticed in 1844 to Messrs. John Penn and Sons, Greenwich. On the completion of his term he left, but returned in 1853 and remained till 1860. He was then appointed manager to the London and Westminster Express Steam Boat Co., and held that position for six years. In 1866 he undertook the management of the works of Messrs. Malo and Co., engineers, at Dunkirk, France; and on the breaking out of the Franco-German war in 1870 he returned to England. He next became manager of the Vauxhall Foundry, Liverpool; and during his engagement there the new era in the transatlantic mail service was inaugurated by the establishment of the White Star line of steamers, of which several of the earlier were engined by the Vauxhall Foundry under his superintendence. In 1873 ill health compelled him to retire from active participation in the management of works of such dimensions; and he returned to London, where he established himself in 1875 as a consulting engineer and steamship surveyor. Having suffered for some months latterly from a complication of diseases, he was seized with apoplexy and paralysis, which terminated in his death at his residence at Leytonstone on 2nd February 1895, in his sixty-seventh year. He became a Member of this Institution in 1878.

Edgar Gilkes was born at Nailsworth, Gloucestershire, on 22nd February 1821. His early engineering training was received at the works of Messrs. Barrett, Exall, and Andrewes, Reading. In 1839 he went to Shildon as an engineer on the Stockton and Darlington Railway; and in 1843 was appointed manager at Middlesbrough of a branch establishment for the repair of rolling stock, under the name of the Tees Engine Works. Shortly afterwards he entered into partnership with Mr. Isaac Wilson for carrying on the works under the name of Gilkes, Wilson and Co.; this venture was the pioneer of the engineering trade on the Tees. For some years the firm assisted Messrs. Robert Stephenson and Co. in making the locomotives used in the North of England. Other work in which they engaged was the construction of viaducts and bridges, including some of the most

noted erections in this country, such as the Deepdale and Beelah viaducts between Barnard Castle and Kirkby Stephen on the North Eastern Railway; also the elegant structure crossing the valley at Saltburn-by-the-Sea, and the Kingston Bridge over the Thames. They also turned out general work, including mill, colliery, and marine engines. In 1852 he followed Mr. John Vaughan in erecting blast-furnaces, called the Tees Iron Works; and two years later more furnaces were erected at Cargo Fleet, under the name of Gilkes, Wilson, Leatham and Co., the discovery of the Cleveland ore having caused the construction of the Guisborough railway, and thus afforded an opening for greater enterprise. He took an active part in the local and municipal affairs of Middlesbrough, and was a county and borough magistrate. In 1882 he removed to Stockton-on-Tees for a few years; but failing health led him to retire from active life, and in 1887 he went to live at Grange-over-Sands. During the last three years he became increasingly an invalid, and after much suffering died at his residence on 18th December 1894, in his seventy-fourth year. He became a Member of this Institution in 1856; and was a Member of Council from 1868 to 1875. He was also President of the Cleveland Iron Masters' Association in 1872.

CARL JOHANN WILHELM GÖTZ was born at Clausthal in the Hartz, Germany, on 31st October 1839. At the age of eighteen he came to this country, and entered the business of Messrs. John M. Sumner and Co., Manchester. There he took an active part in the export engineering branch, becoming eventually a partner in the firm. His death took place at Whalley Range, Manchester, on 20th February 1895, in his fifty-sixth year. He became an Associate of this Institution in 1889.

CHRISTOPHER JAMES was born at Merthyr Tydfil, on 17th March 1836, and was the youngest son of Dr. Job James, naval surgeon, of that town. After leaving school he spent a year at Bonn University, and some time in Paris. He then served his apprenticeship with Messrs. Sharp, Stewart and Co., Manchester; and on its termination went to the United States and Canada for two years, where he

acquired a wide experience in mechanical work. On returning home he spent three years in Bridgewater, and then settled in Bristol as a consulting engineer. In this capacity he designed the buildings and the chief part of the machinery and plant for Messrs. Christopher Thomas and Brothers' Broad Plain Soap Works, and built two of the largest chimneys in the district for the Netham Chemical Works, acting as consulting engineer to these works as well as to breweries, sugar refinery, brickworks, and various other concerns. He designed a steam-jet blowing and exhausting apparatus, and annealing furnaces and grates. His death occurred at his residence in Clifton, Bristol, on 27th January 1895, in his fifty-ninth year. He became a Member of this Institution in 1877.

ARTHUR PAGET was born at Leicester on 15th October 1832. In 1848 he became a student in the applied sciences department at Kings' College, London, remaining there three years, and then served a pupilage of three years with Messrs. Sharp, Stewart, and Co., Manchester. In 1854 he went to Loughborough, and was for two years engineer and manager, and for five years managing partner, in the firm of Messrs. Paget and White. In 1866 he started business there on his own account as an engineer and machinist, taking up a branch of engineering to which some of his ancestors had devoted much attention—the manufacture of knitting, weaving, and other textile machinery; and many improvements of more or less importance are due to his inventive powers. In 1870 he introduced his self-acting machine for knitting hosiery by steam power, of which he gave an account in a paper read at the meeting of this Institution in Nottingham (Proceedings 1870, page 127). The success attained with this knitting machinery encouraged him still further in his experiments towards the construction of the machine for warp weaving and knitting without weft, which was produced and shown at the Paris Exhibition in 1889, and was described at the Paris meeting in that year (Proceedings 1889, page 469). The mechanical ingenuity displayed, and the extreme accuracy and precision of the workmanship, were highly appreciated, and gained for him the

decoration of Chevalier of the Legion of Honour. The research work conducted by this Institution had its origin largely in his initiative; and for the investigation of the hardening of steel he undertook in 1881, in connection with Sir Frederick Abel, a series of tests to determine thoroughly the difference in percentage of carbon between samples of steel annealed or hardened by different processes, and also to ascertain with more precision how far the separation of the carbide in different preparations was an indication of different temper in the steel (Proceedings 1881, pages 696–9; 1882, pages 147–9; and 1885, pages 30, 49, 54). Subsequently he made 900 experiments to ascertain the proper co-efficient of friction of various sorts of ropes on pulleys under different circumstances; but the results, even under similar conditions, were too varying to tabulate or admit of deductions. He was one of the first and most vigorous promoters of the movement for transferring the headquarters of this Institution from Birmingham to London, the removal being ultimately carried out in 1877. For some years past he had not enjoyed good health, and recently had suffered from a stroke of paralysis, which affected his speech and deprived him of the power of one side, his heart being also affected. His death occurred from apoplexy on 25th March 1895, at the age of sixty-two. He became a Member of this Institution in 1868, and was a Member of Council from 1878 to 1886, and a Vice-President from 1887 to 1891.

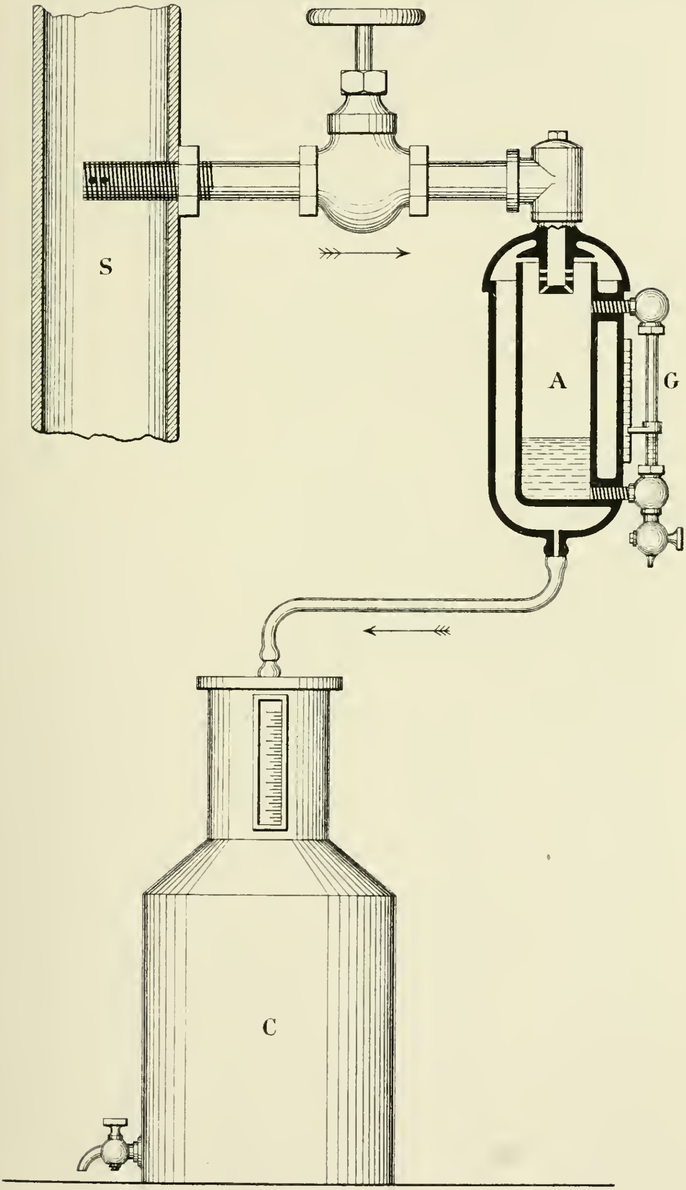
JOHN RICHARD RAVENHILL was born at Lavender Sweep, Clapham, London, on 15th April 1824, and was the eldest son of John Ravenhill of Ashton Gifford, Wiltshire. He was educated at Winchester College, and completed his education as a civil engineer at King's College, London. He was then employed at his uncle's works, Orchard Wharf, Blackwall, and Glass House Fields, Ratcliff; and in 1853 became a partner in the firm of Miller, Ravenhill and Co. In this position, and afterwards as head of the firm of Ravenhill, Hodson and Co., he completed large contracts for marine engines for the Admiralty, and for many shipping companies and private firms. In 1874 he retired from engineering business, and for some time filled the position of engineer assessor in the Wreck Commissioners' Court;

and was also a member of the Thames Conservancy Board. His death took place at his residence at Delaford, Iver, near Uxbridge, on 28th December 1894, in his seventy-first year. He became a Member of this Institution in 1862; and was a Member of Council of the Institution of Naval Architects, and a Member of the Institution of Civil Engineers.

EDWARD REYNOLDS was born in London on 7th October 1825. His boyhood was spent in Herefordshire, where he went to school; and he completed his education at King's College, London. In 1844 he was apprenticed to Messrs. Adams and Co., engineers and carriage builders, Old Ford, London, and remained there for two years. During this period he had the opportunity of becoming acquainted with early experiments on Henson's flying machines, with which the firm were concerned. In 1846 he became chief draughtsman in the locomotive department of the Eastern Counties Railway, where he remained till 1850; and he was instrumental in the alteration of the locomotives from the then 5 feet 9 inches gauge, having bar frames, to the 4 feet 8½ inches gauge, which necessitated the substitution of slab frames. From 1850 to 1852 he was draughtsman and manager of Mr. Thomas Kennard's office, Adelphi, London, where he was largely engaged in designing Warren girder bridges and bridges generally. From 1852 to 1860 he was chief engineer to the Butterley Iron Co., near Alfreton, and during this period he remodelled a large portion of their machinery, some of which was antiquated; several of the engines and locomotives he designed are still at work there. In 1860 he joined Mr. (now Sir Frederick) Bramwell in partnership, which continued until early in 1863, when he became engineer to Messrs. Naylor, Vickers and Co., Millsands, Sheffield, and was engaged in the construction of their River Don Works. In 1872 he became a managing director, and continued in this position for the rest of his life. Among the more noticeable machines designed by him at these works are the large forging presses, the construction of which was commenced in 1882; they have a long-stroke ram, bearing against the spherical end of an inverted T shaped cross-head, which works between guides and

carries the forging face. Before the actual pressing, the slack is taken up by water at a lower pressure; this plan he had adopted some time before for general hydraulic work, possessing as it does the advantage that smaller pumping engines can be employed. In 1894 he became a director of the Elmore Copper and Wire Companies, and took an active interest in their management and in the technicalities of their manufacture. During the latter part of 1894 his health had been failing, and a chill contracted at the beginning of the present year hastened his death, which took place at Sheffield on 12th January 1895, in his seventieth year. He became a Member of this Institution in 1862, and was also a Member of the Institution of Civil Engineers, the Institution of Naval Architects, and other kindred societies.

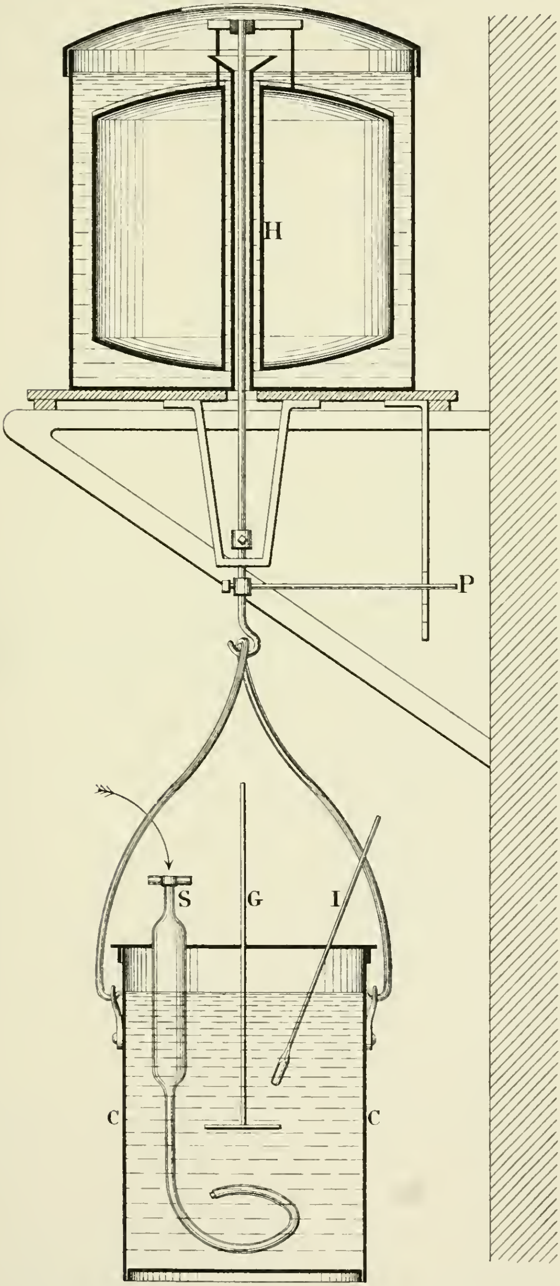
Fig. 1. *Carpenter Separating Calorimeter.*



Mechanical Engineers 1895. *Scale 1/4 th.*

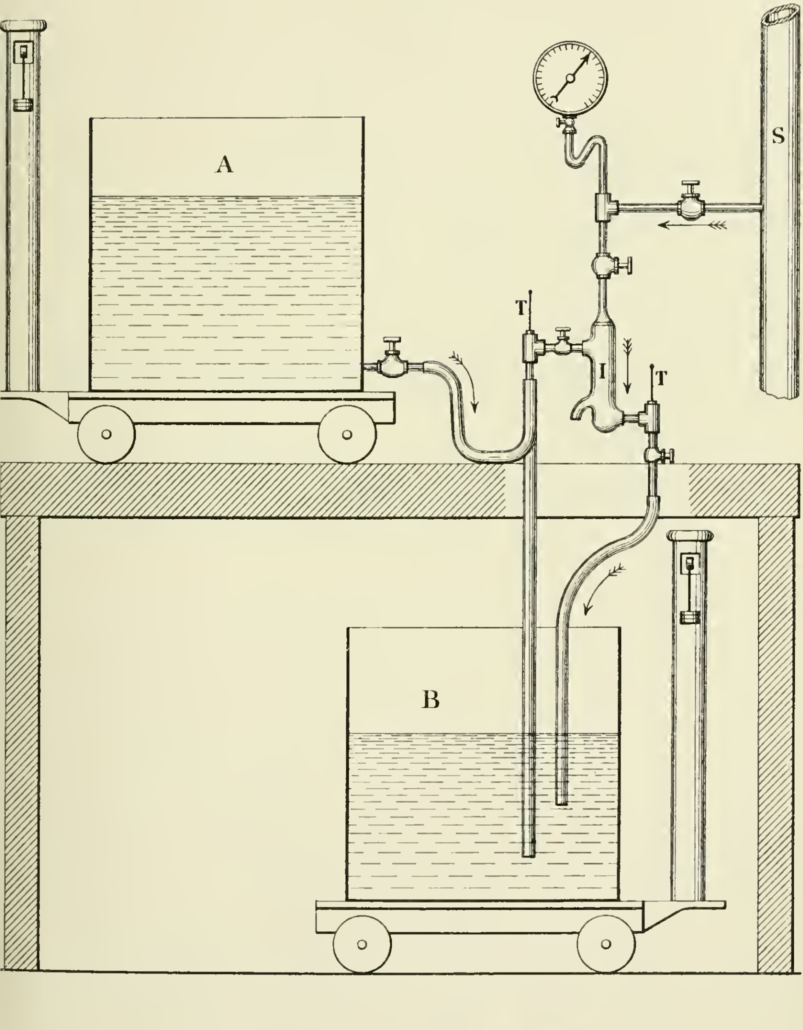
0 1 2 3 4 5 6 7 8 9 10 11 12 Inches

Fig. 2. *Hirn Condensing Calorimeter.*



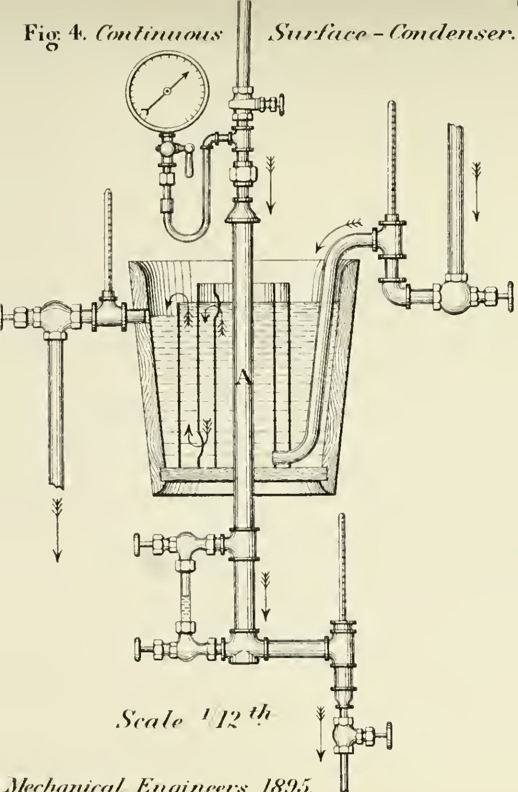
Mechanical Engineers 1895. *Scale 1/10th.*

Fig: 3. *Continuous Injection-Condenser.*



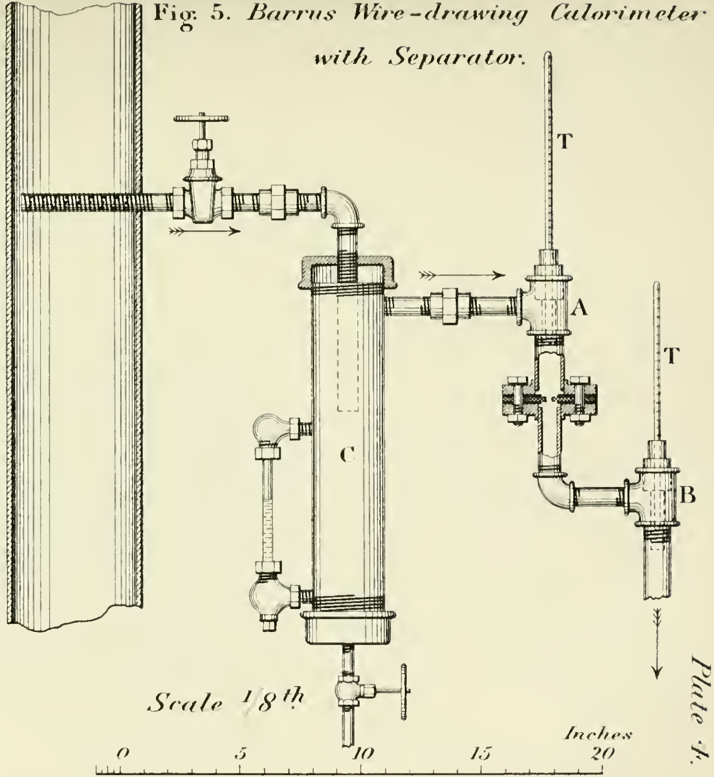
Mechanical Engineers 1895. *Scale 1/20th.*

Fig. 4. *Continuous Surface-Condenser.*



Scale 1/12th.

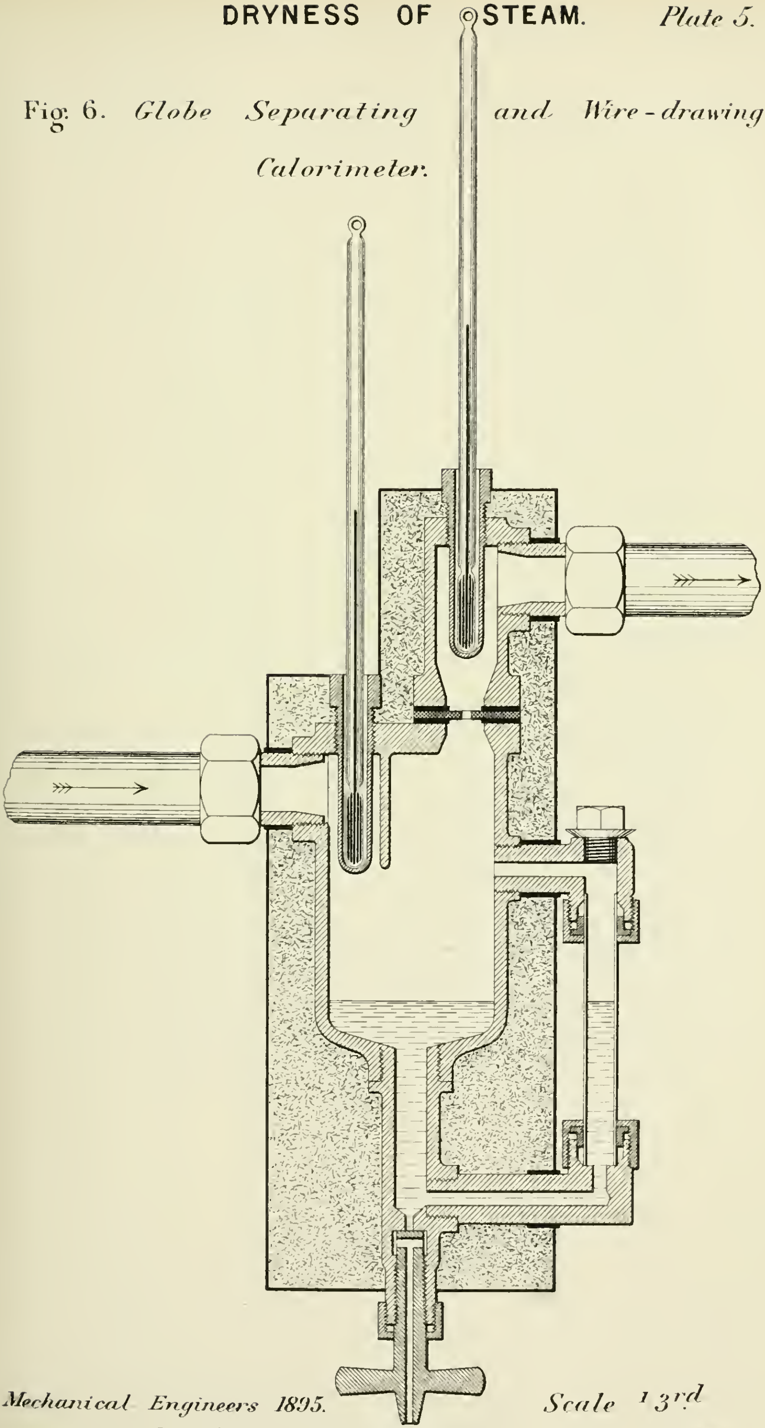
Fig. 5. *Barrus Wire-drawing Calorimeter with Separator.*



Scale 1/8th.

Plate 4.

Fig. 6. *Globe Separating and Wire-drawing Calorimeter.*

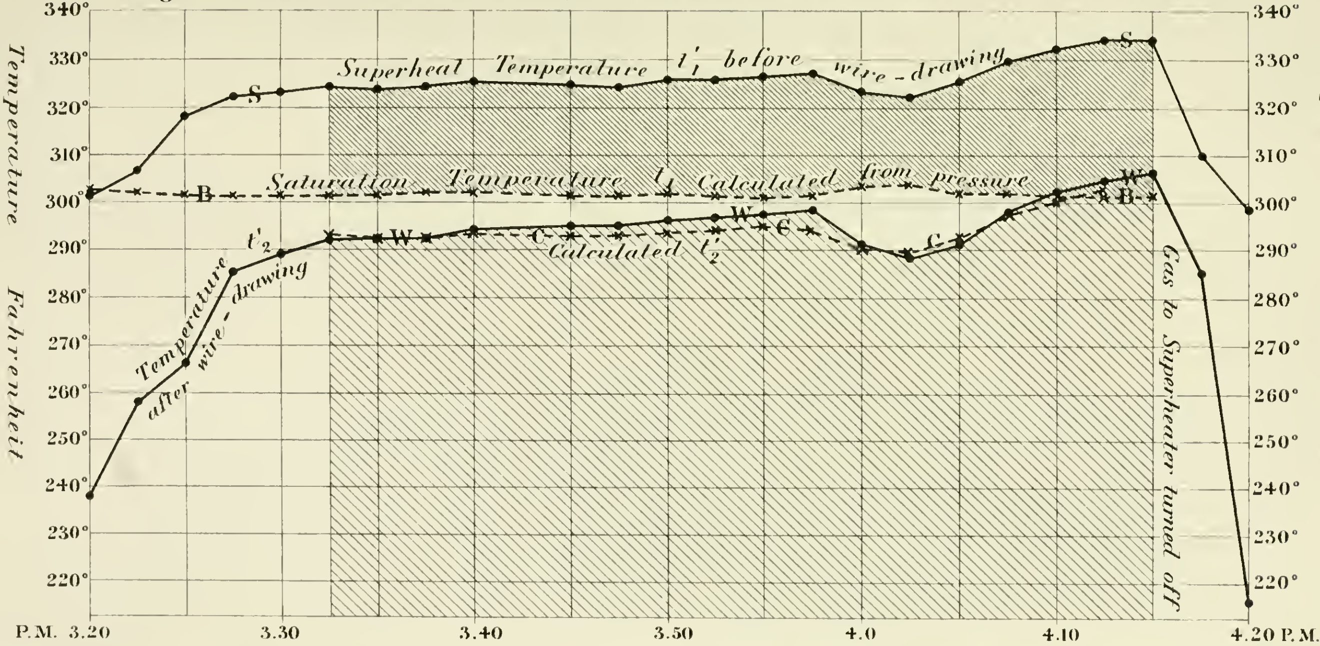


Mechanical Engineers 1895. *Scale 1/3rd.*

0 1 2 3 4 5 6 7 8 Inches

DRYNESS OF STEAM.

Fig. 7. *Barrus Wire-drawing Calorimeter using Superheated Steam.*

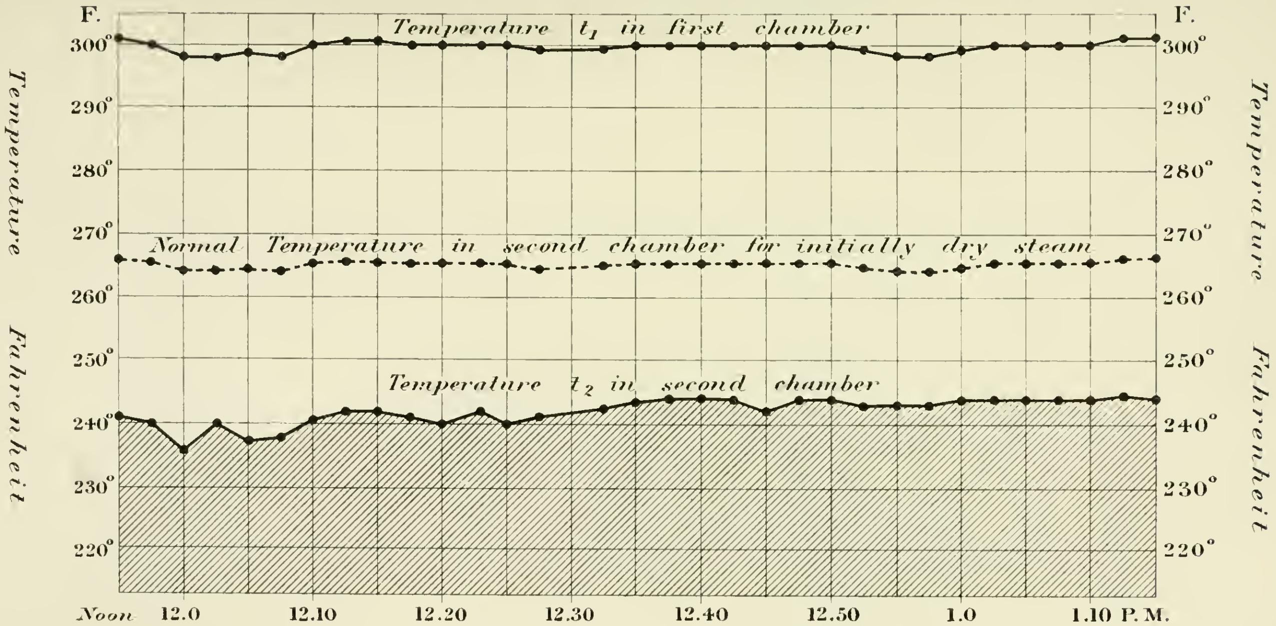


Steam valve opened 2.49 P. M. *Gas to Superheater lighted at* 3.1 P. M.

Plate 6.

DRYNESS OF STEAM.

Fig: 8. *Wire-drawing Calorimeter using wet steam.*

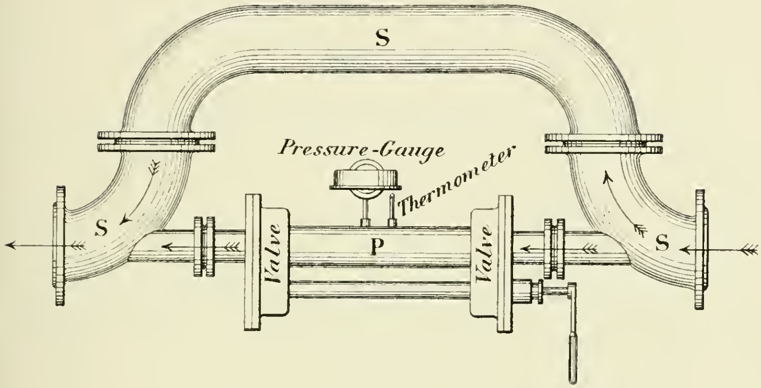


Steam valve to Calorimeter opened 11.25 A. M. *Saturation Temperature in second chamber* 213°

Plate 7.

Fig. 9. *Gehre Apparatus*

for measuring quantity of priming water.



Scale 1/12th.

Fig. 10. *Steam-pipe in experimental boiler.*

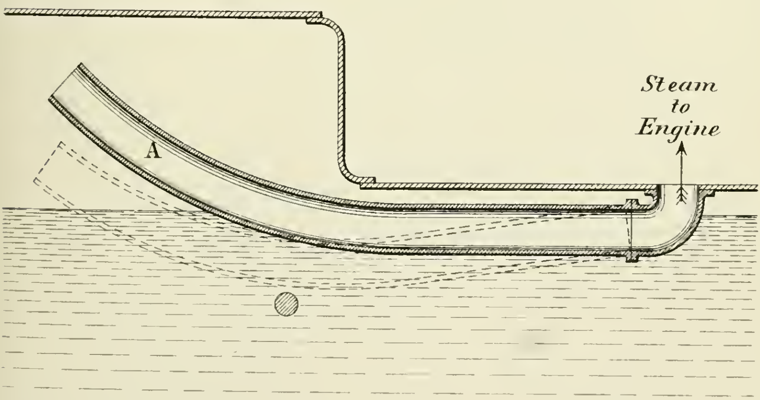
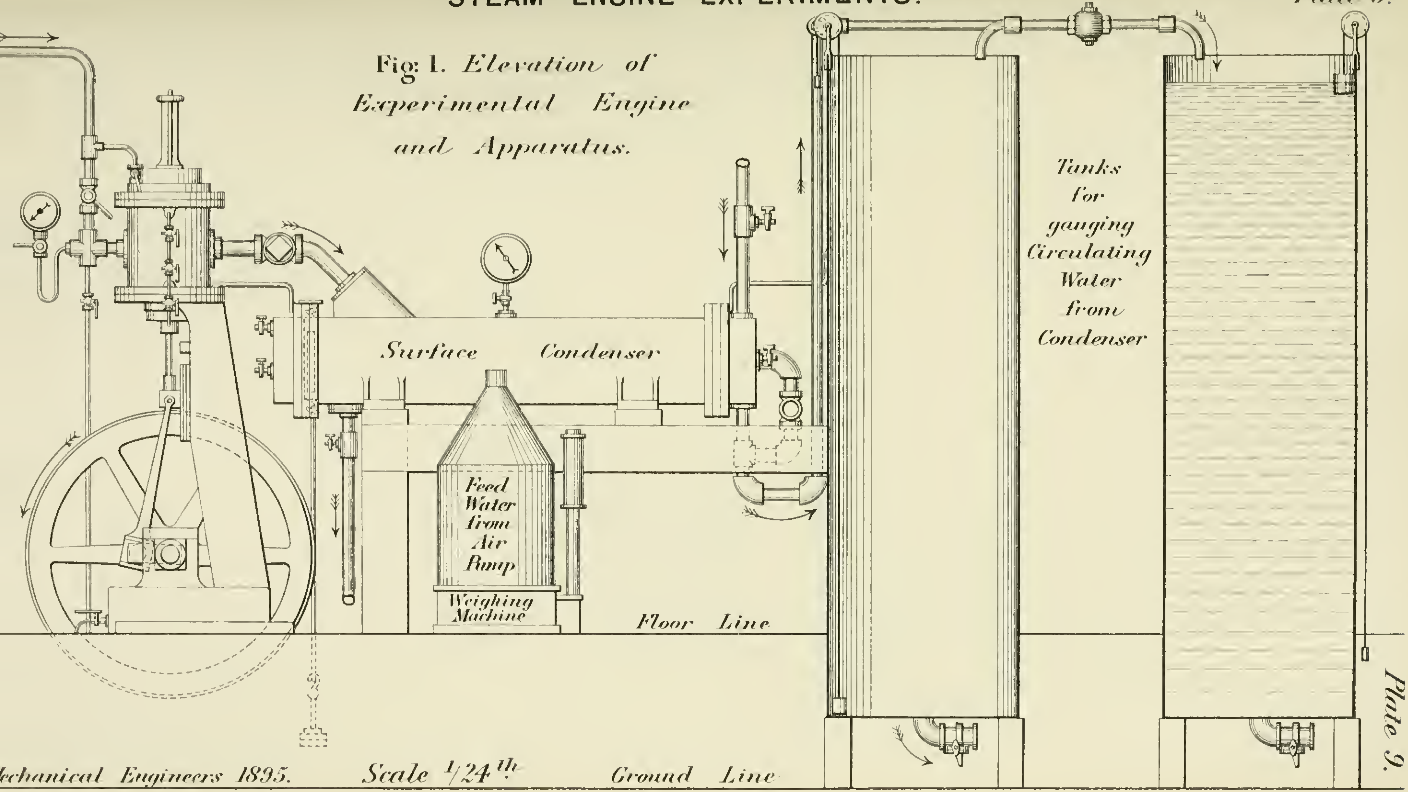


Fig: 1. *Elevation of Experimental Engine and Apparatus.*



Scale 1/24th.

Plate 9.

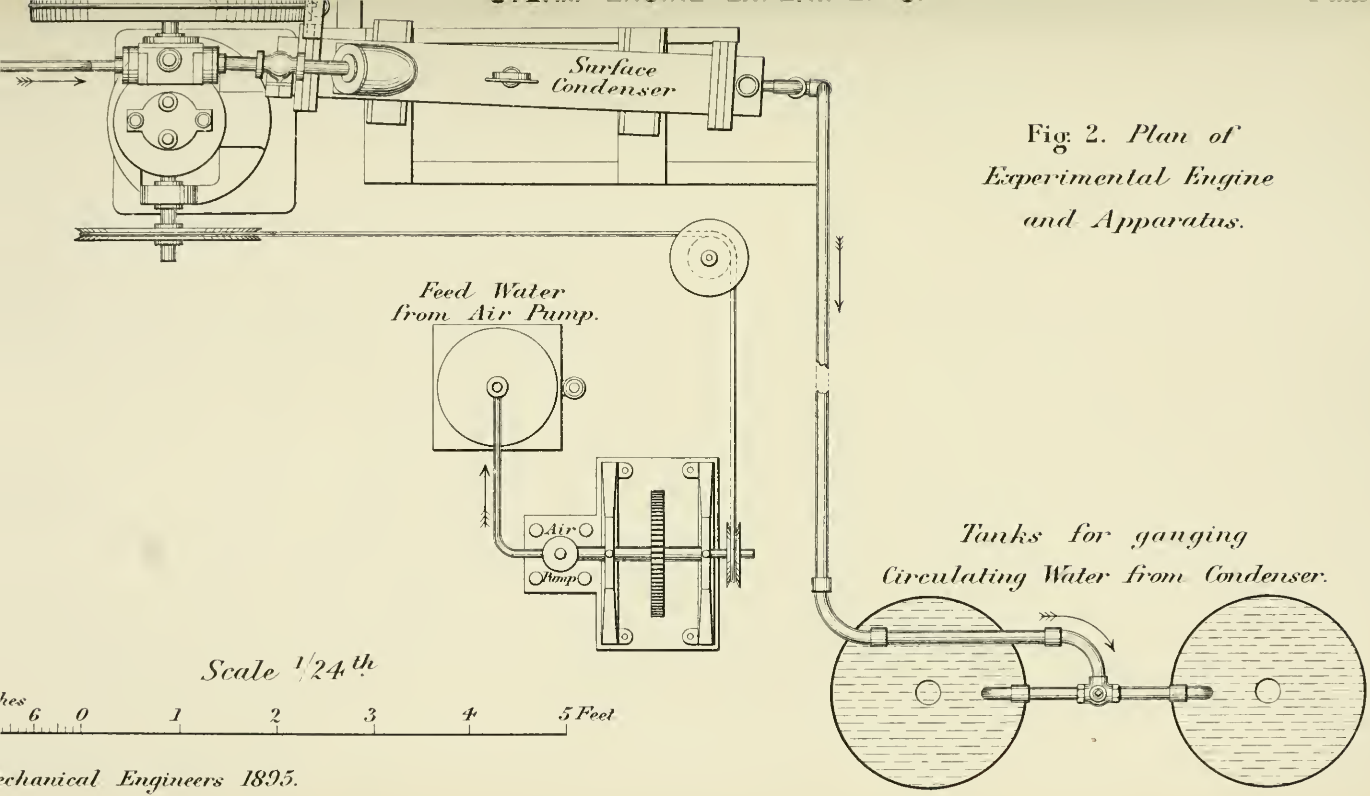


Fig. 2. *Plan of Experimental Engine and Apparatus.*

Fig. 3. *Clearance and Cylinder Surface exposed to Steam during stroke.*

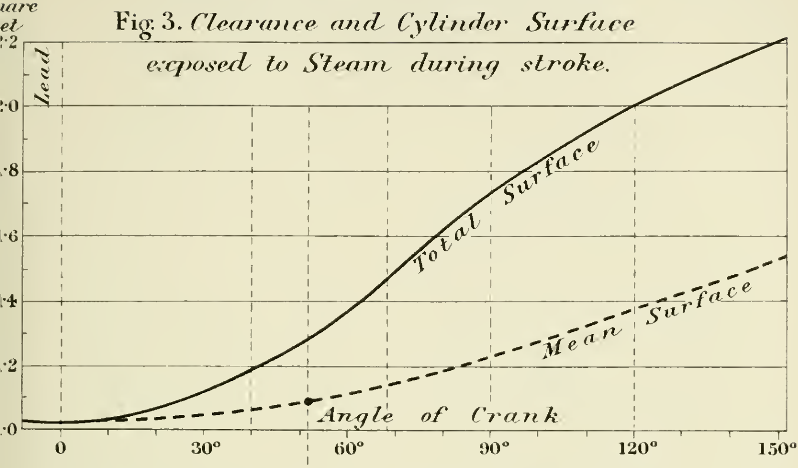
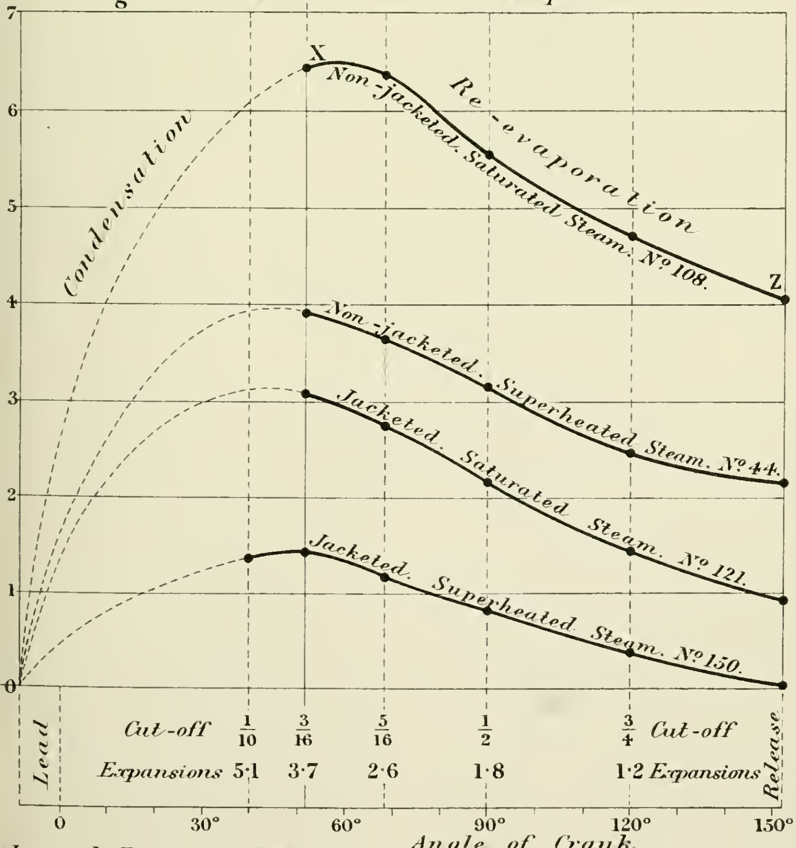


Fig. 4. *Condensation and Re-evaporation.*



Thermal Gradients through Walls.

Fig: 5. *Series* 1. *Non-Jacketed.*

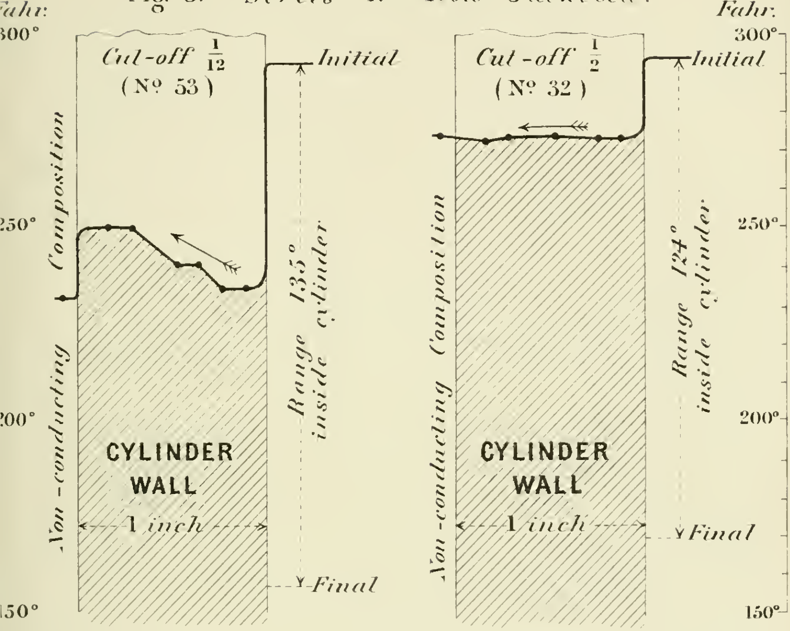
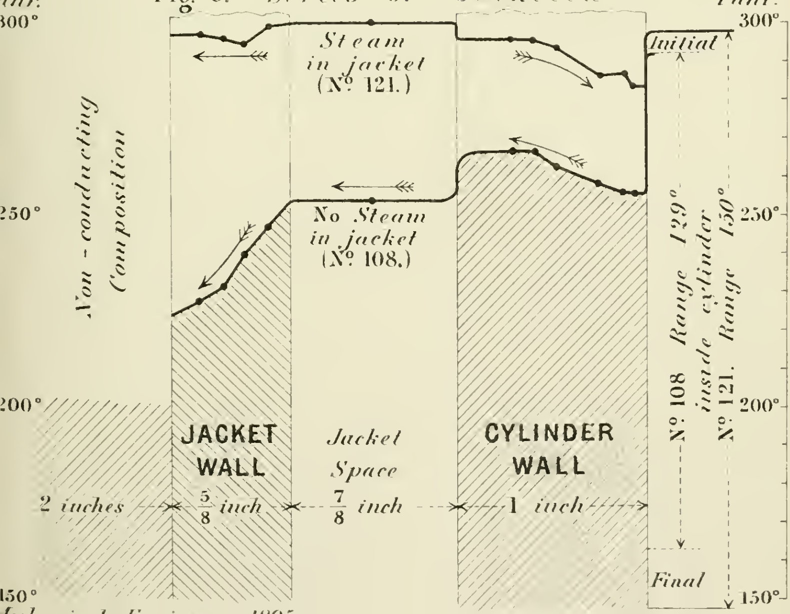
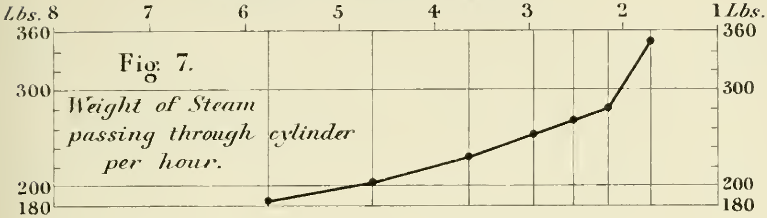


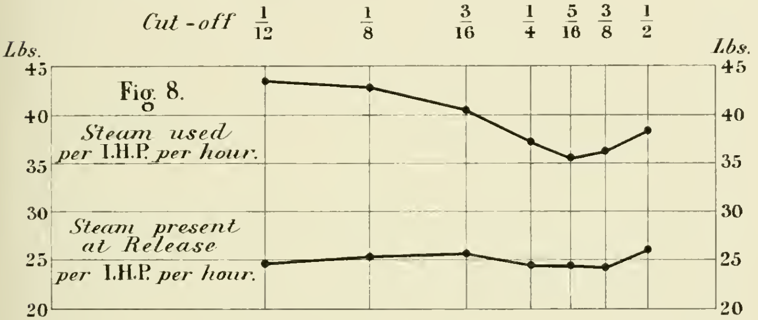
Fig. 6. *Series* 9. *Jacketed*

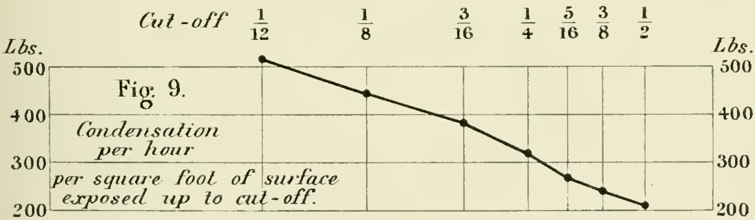


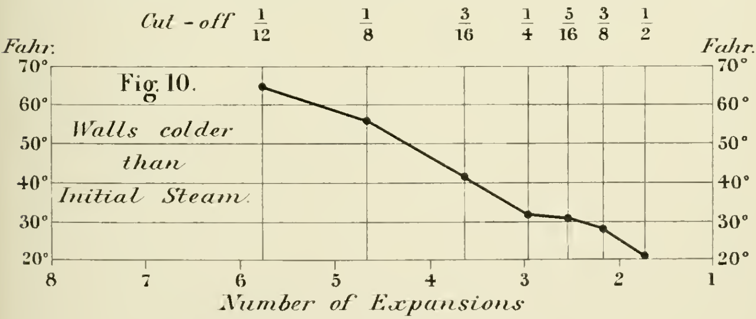
STEAM-ENGINE EXPERIMENTS. *Plate 13.*

Results of Series 1. Non-jacketed.









Appearance of Condensation.

Fig. 11.

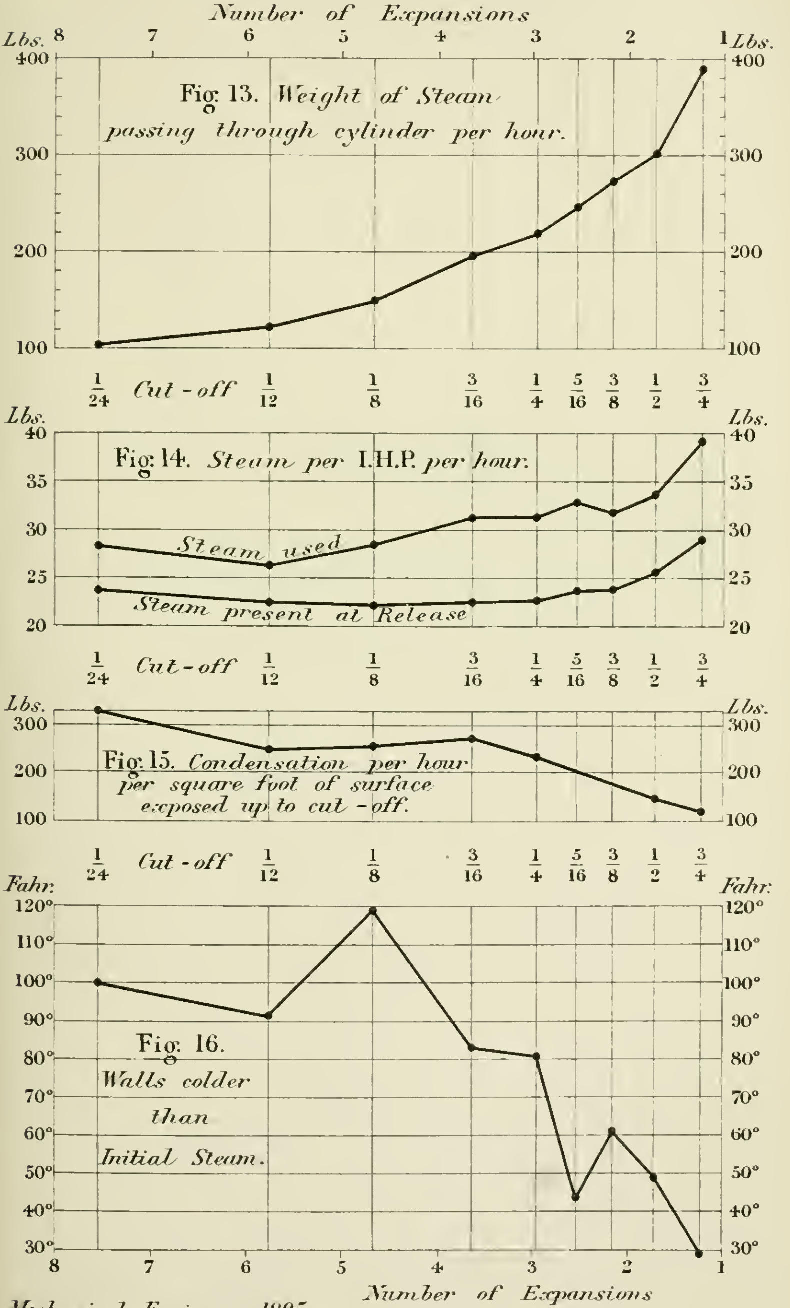
No. 53. 

Fig. 12.

 No. 37.

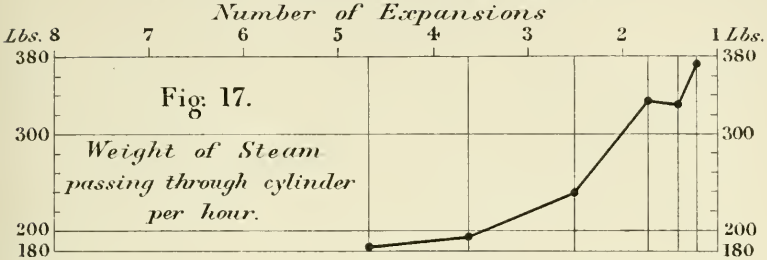
STEAM-ENGINE EXPERIMENTS. *Plate 14.*

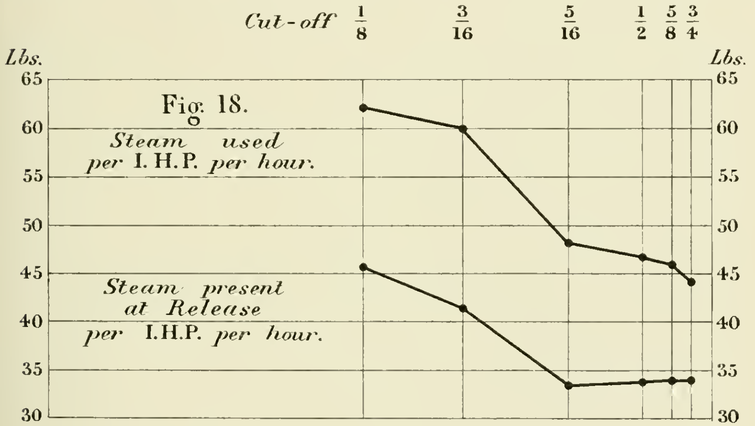
Results of Series 2. Non-Jacketed.

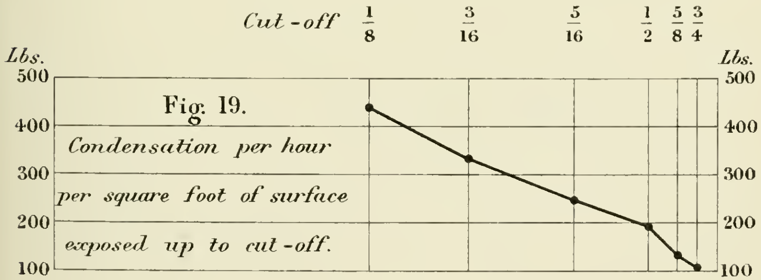


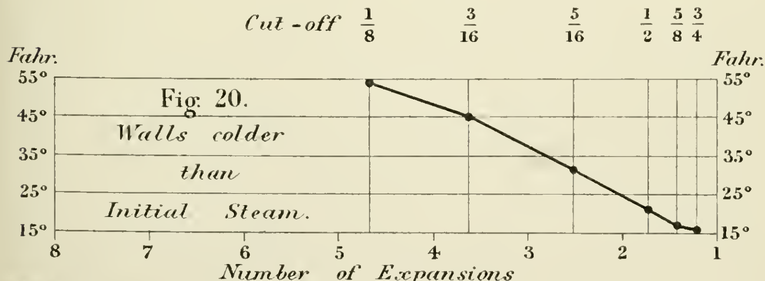
STEAM-ENGINE EXPERIMENTS. *Plate 15.*

Results of Series 3. Non-jacketed.



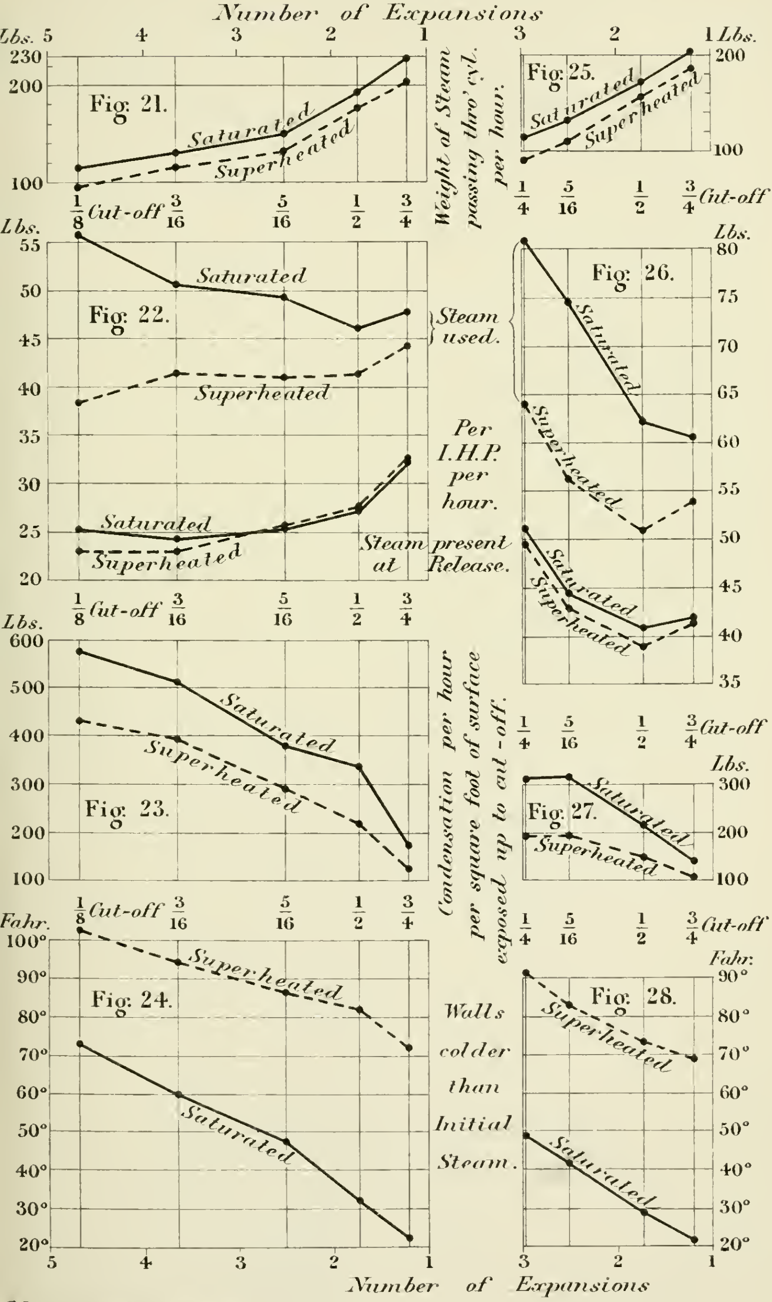






STEAM-ENGINE EXPERIMENTS. *Plate 16.*

Series 4 and 5. Non-jacketed. Series 6 and 7.



STEAM-ENGINE EXPERIMENTS. *Plate 17.*

Results of Series 9. Jacketed.

Fig: 29. *Weight of Steam passing through per hour.*

Fig: 30. *Steam used er I.H.P. per hour.*

Fig: 31. *ondensation per hour er sq. ft. of surface xposed up to cut-off.*

Fig: 32. *Walls colder than Initial Steam.*

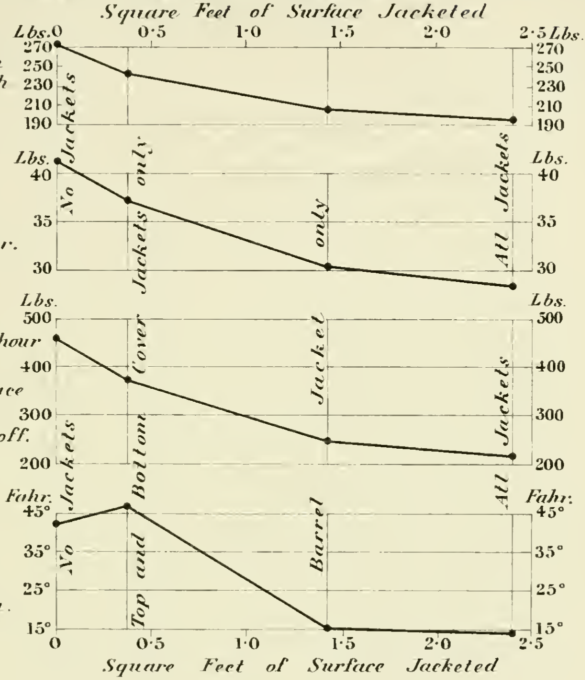
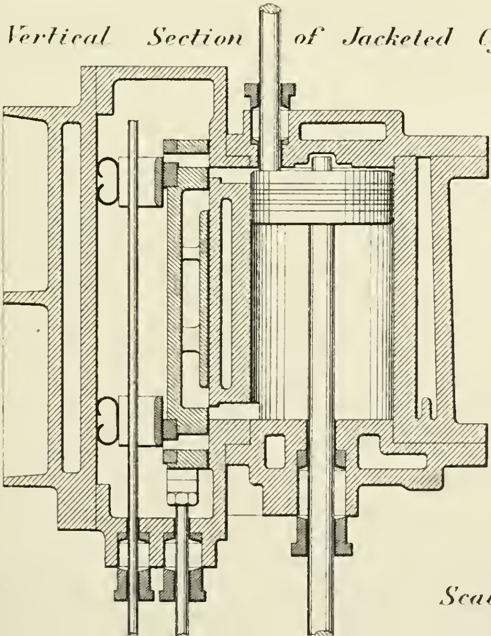


Fig. 33. *Vertical Section of Jacketed Cylinder.*



Scale 1/8th.

STEAM-ENGINE EXPERIMENTS. *Plate 18.*

Results of Series 10. Jacketed.

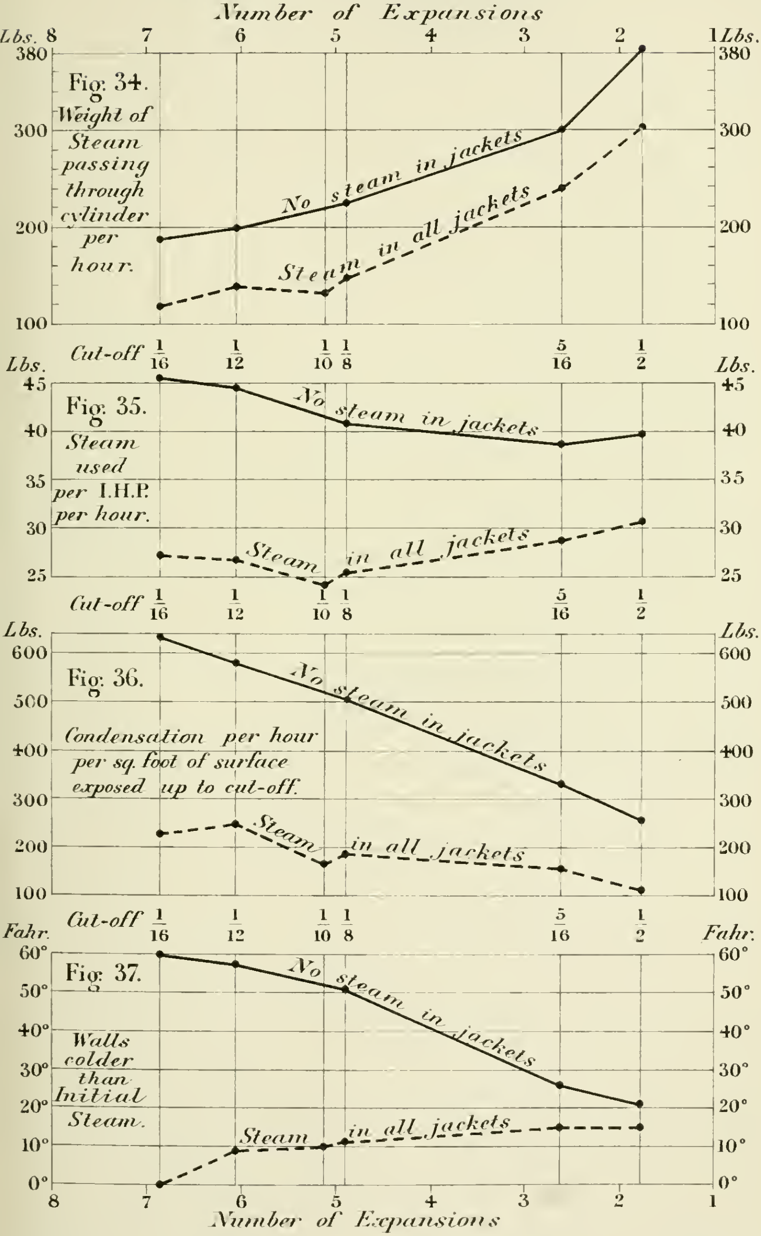
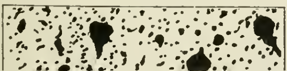
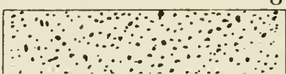


Fig. 38. *Appearance of Condensation.* Fig. 39.

No. 130.

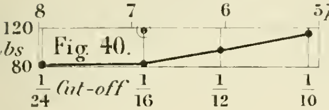




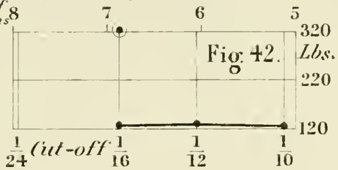
No. 136.

Results of Series II. Jacketed.

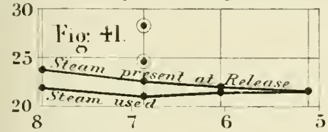
Weight of Steam passing through per hour.



Condensation per hour per sq. ft. of surface exposed up to cut-off.

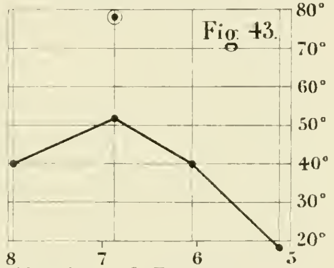


Lbs. Steam per I.H.P. per hour.



Number of Expansions

Walls colder than Initial Steam. Fahr.



Number of Expansions

Fig. 44.

Appearance of Condensation.

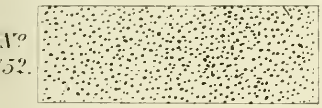
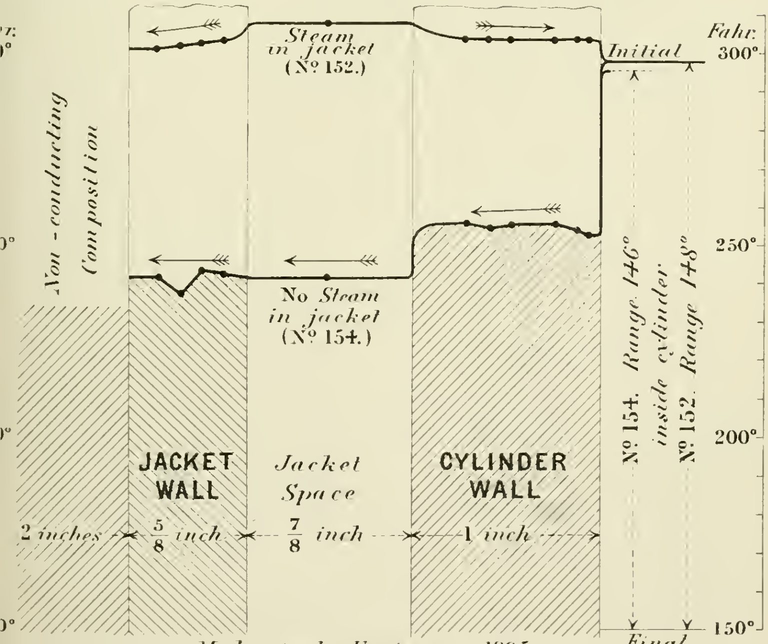


Fig. 45. *Thermal Gradients through Walls.*



Institution of Mechanical Engineers.

PROCEEDINGS.

April 1895.

The Spring Meeting of the Institution was held in the Lecture heatre of the Royal United Service Institution, Whitehall, ondon, on Wednesday, 24th April 1895, at Half-past Seven o'clock m.; Professor Alexander B. W. Kennedy, LL.D., F.R.S., resident, in the chair.

The Minutes of the previous Meeting were read, approved, and gned by the President.

The President announced that the Ballot Lists for the election New Members had been opened by a committee of the Council, d that the following forty-four candidates were found to be duly ected:—

MEMBERS.

Benn, Sykes,	Haslingden.
Britten, Thomas Johnson,	Johannesburg.
Daintree, Thomas Ekins,	Johannesburg.
Elliott, George,	Belfast.
Geach, Frederick Samuel,	Pontypool.
Greensmith, James Eades,	Portland, U.S.A.
Isaac, Robert,	Portmadoc.
Johnstone, Capt. J. H. L'E., R.E.,	London.
Livingston, James,	London.
Proctor, Charles Faraday,	London.
Redit, David,	Downham Market.
Richardson, Andrew,	Singapore.

Robinson, James, ...	Hartlepool.
Stromeyer, J. P. Edmond Charles, .	Glasgow.

ASSOCIATE MEMBERS.

Armstrong, George Edwin, . .	Brighton.
Barnes, James, ...	Manchester.
Bennis, Alfred William, . .	Bolton.
Boulden, Frederick, . . .	Sheffield.
Cust, Leopold, ...	London.
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Russell, Frederick, . . .	Bexhill-on-Sea.
Threlfall, George, . . .	London.
Wasdell, Abel, ...	Allahabad.

GRADUATES.

Blair, George, ...	Glasgow.
Clarke, Leigh Theophilus, . .	Horwich.
Connell, William Percival, . .	Huelva.
Gale, Robert Henry, . . .	London.
Griffiths, Alfred, . . .	Manchester.
Maia, Honorio de Aranjo, . .	Bolton.
Pearce, Herbert, ...	London.
Rayner, Harry Stafford, . .	London.
Roberts, Basil Owen, . . .	Melton Constable.
Williams, Spencer, ...	London.

The Discussion upon Capt. Sankey's Paper on Governing of Steam ngines by Throttling and by Variable Expansion, which had been ljourned from the Annual General Meeting, was resumed and ncluded.

At a Quarter past Nine o'clock the Meeting was adjourned to riday evening. The attendance was 72 Members and 56 Visitors.

The Adjourned Meeting was held at the Royal United Service ıstitution, London, on Friday, 26th April 1895, at Half-past Seven clock p.m.; Professor Alexander B. W. Kennedy, LL.D., F.R.S., resident, in the chair.

The following Paper with Appendices was read and discussed:—

Third Report to the Alloys Research Committee;" by Professor W. C. Roberts-Austen, C.B., F.R.S.

Appendix on the Elimination of Impurities during the process of making *Best Selected* Copper;" by Mr. Allan Gibb, A.R.S.M.

Appendix on the Pyrometric Examination of the Alloys of Copper and Tin;" by Mr. Alfred Stansfield, A.R.S.M.

The Meeting then terminated at a Quarter to Ten o'clock. The ttendance was 70 Members and 41 Visitors.

The Anniversary Dinner of the Institution was held at The Freemasons' Tavern, Great Queen Street, Lincoln's Inn Fields, on Thursday evening, 25th April 1895, and was largely attended by the Members and their friends. The President occupied the chair; and the following Guests accepted the invitations sent to them, though those marked with an asterisk* were unavoidably prevented at the last from being present. Mr. Leslie Stephen; Mr. S. B. Bancroft; The Right Honourable the Lord Provost of Edinburgh; Sir Frederick A. Abel, Bart., K.C.B., D.C.L., D.Sc., F.R.S., Honorary Life Member; Sir Richard E. Webster, G.C.M.G., Q.C., M.P.; Sir Henry E. Roscoe, M.P., D.C.L., LL.D., F.R.S.; Sir Samuel Black, Town Clerk of Belfast; Sir Renny Watson, Chairman of the Glasgow Meeting Committee; Mr. Edmund Boulnois, M.P.; Dr. Michael Foster, F.R.S., Secretary of the Royal Society; Mr. J. Fletcher Moulton, Q.C., M.P., F.R.S.

Sir Robert Rawlinson, K.C.B., President of the Institution of Civil Engineers; Rear-Admiral H. F. Cleveland, R.N., Chairman of Council, Royal United Service Institution; Mr. T. Chatfeild Clarke,* President of the Surveyors' Institution; Mr. E. Windsor Richards, President of the Iron and Steel Institute; Mr. R. E. B. Crompton, President of the Institution of Electrical Engineers; Mr. W. Lloyd Wise, President of the Chartered Institute of Patent Agents; Mr. Frank H. Pearson, President of the Hull and District Institution of Engineers and Naval Architects; Mr. J. H. Collins, President of the Institute of Mining and Metallurgy; Lieut. Gerald R. Maltby, R.N., Secretary of the Royal United Service Institution; Mr. Julian C. Rogers,* Secretary of the Surveyors' Institution.

Professor Archibald Barr, Honorary Secretary of the Glasgow Meeting Committee; Professor David S. Capper, King's College, London; Mr. Michael Carteighe, F.C.S.; Professor Olaus Henrici, F.R.S., City and Guilds of London Central Institution; Professor D. E. Hughes, F.R.S.; The Rev. John Kennedy,* D.D.; Mr. J. Lumsden Propert, M.D.; Professor William Ramsay, F.R.S., University College, London; Professor A. W. Rücker, F.R.S.; Mr. Basil Slade; Mr. James Swinburne; Professor Silvanus

Thompson, D.Sc., F.R.S., Principal of the City and Guilds of ıdon Technical College; Mr. Charles J. Wilson, F.I.C.

Professor W. C. Roberts-Austen, C.B., F.R.S., Chemist to the yal Mint; Capt. H. Riall Sankey; Mr. Allan Gibb; Mr. Alfred nsfield; Mr. William Gowland; Mr. Reginald A. Roberts.

The President was supported by the following Officers of the titution:—*Past-Presidents,* Dr. William Anderson,* F.R.S.; Edward H. Carbutt, Bart.; Mr. Jeremiah Head *; and Mr. Percy B. Westmacott.* *Vice-Presidents,* Sir Douglas Galton, K.C.B.,).L., LL.D., F.R.S.; Mr. Edward P. Martin*; and Mr. E. Windsor hards. *Members of Council,* Mr. John A. F. Aspinall, Mr. William ın, Mr. Bryan Donkin, Mr. Arthur Keen, Mr. John G. Mair-mley, Mr. James Platt, Mr. T. Hurry Riches,* and Mr. A. ınett Walker.

After the usual loyal toasts, Sir Henry E. Roscoe, M.P., D.C.L., .D., F.R.S., proposed that of "Scientificand Professional Societies," ich was acknowledged by Dr. Michael Foster, F.R.S., Secretary of Royal Society, and by Rear-Admiral H. F. Cleveland, R.N., airman of Council, Royal United Service Institution. The toast ' Scientific and Technical Research," proposed by Mr. J. Fletcher ulton, Q.C., M.P., F.R.S., was acknowledged by Professor lliam Ramsay, F.R.S., and Professor W. C. Roberts-Austen, C.B., R.S. Sir Douglas Galton, K.C.B., D.C.L., LL.D., F.R.S., Vice-esident, proposed the toast of "Our Guests," which was acknowledged Mr. S. B. Bancroft, and Professor A. W. Rücker, F.R.S. The ıcluding toast of "The Institution of Mechanical Engineers" was posed by Mr. Leslie Stephen, and acknowledged by the President.

GOVERNING OF STEAM ENGINES BY THROTTLING AND BY VARIABLE EXPANSION.

By Capt. H. RIALL SANKEY, of Thames Ditton.

In the present paper it is intended to consider certain points in connection with the two usual methods of Governing a steam engine; and it will be attempted to show that, although for many purposes the popular verdict in favour of Variable-Expansion Governing may be accepted, yet its advantages are commonly much overrated, and in some cases it has no advantage at all. Governing by Throttling may with convenience be described as constant expansion with variable pressure; while the system commonly called automatic is constant pressure with variable expansion. A complete comparison of the two methods would require a consideration of the following points:—(1) the effect on the steam consumption of the engine; (2) the effect on the closeness of governing, as regards both sudden and gradual changes of load; (3) the relative capabilities to deal with overloading; (4) the relative simplicity and reliability of the various gears from the mechanical point of view; (5) the first cost. It is not intended to describe any of the numerous gears which have been devised with more or less success for governing engines by either method, though undoubtedly the closeness of governing is more affected by the nature of the gear than by whether it acts on the throttle or on the expansion; it will be understood that the comparison is made between gears the best of their kind. The question of cost will not be considered, as it depends on the nature of the gear. The paper will therefore deal with the first three points only.

Governing by variable cut-off is generally considered to be superior to throttle governing, and the latter is looked upon by many engineers as fit for second-rate engines only. The principal reason for this preference appears to be the supposed great superiority in steam consumption of an engine governed by the cut-off; and the feeling is no doubt natural enough that pressure is being wasted when working at less than full load and governing by the throttle. As a rule, indicator diagrams from engines with variable-expansion gears look better, but they are often cloaks for exaggerated initial condensation: that is to say, the weight of steam shown by the indicator to be present in the cylinder at cut-off may be as small as can be desired, and much less than that shown by a throttled diagram of the same area; and yet it may be found, by comparison with the actual feed-water used, that the real consumption of steam per indicated horse-power is nearly as large, owing to excessive initial condensation; the indicator shows how much *steam* is present, but it tells nothing about the water. Hence the supposed gain over throttling, as regards steam consumption, is smaller than might be estimated, judging from the diagrams only. In fact no conclusion as to economy can be derived from the diagrams only—a truth which cannot be too strongly emphasized, and the neglect of which leads to constant misunderstanding and error.

Nevertheless when an engine is working against a very variable load, and it is expedient to realize the greatest economy at some load less than the fullest load which the engine is mechanically capable of developing, then governing by variable expansion has advantages: because it may be stated broadly that in a throttling engine the fullest load is the most economical load.

The present paper may be looked upon as an elaboration of section F of the late Mr. P. W. Willans' paper on Steam-Engine Trials, read before the Institution of Civil Engineers in April 1893 (Proceedings, vol. cxiv, page 40). That section treats of "the economical value of automatic expansion-gear as a means of reducing the power"; and all the numerical results about to be given in this paper are based on Mr. Willans' experiments on non-condensing and condensing engines. The author was unable to obtain any other

experiments sufficiently complete for his purpose; but there can be no reasonable doubt that the principal conclusions here arrived at apply to any engine, although the absolute results will be different. To save repetition, it is to be understood that the numerical results apply strictly to Willans engines only.

Economy.—The indicated horse-power of an engine of given cylinder volume depends on two factors, namely the number of revolutions and the mean pressure. If, in order to alter the power, the speed is varied and the mean pressure maintained constant, the steam consumption per indicated H.P., and equally per brake H.P., will be increased but slowly as the load is diminished: * for the reason that, other things being equal, high speed of rotation is in itself more economical than low speed, the initial condensation being smaller owing to the shorter exposure of the surfaces to exhaust temperature. If however the speed is constant, the mean pressure must be varied for variations in the load; and in this case the steam consumption per indicated H.P. will depend much more upon the load, and will increase in general as the load diminishes, the increase, especially per brake H.P., being rapid at light loads. The mean pressure can be varied either by keeping the cut-off constant and varying the initial pressure, or by varying the cut-off and keeping the initial pressure constant. The present object is to enquire which of these two methods of altering the mean pressure gives the best economical results under various conditions. It will be seen that the answer is not the foregone conclusion it is sometimes supposed to be.

As a preliminary it may be interesting to enquire into the matter from a purely theoretical point of view. In his remarks on Mr. Willans' paper read before the Institution of Civil Engineers (Proceedings, vol. cxiv, page 96), the author showed that the total water consumption per hour of a theoretical constant-expansion engine

* This point was brought out clearly by Mr. Willans, both in his non-condensing and in his condensing trials. In the latter, for instance, he showed that in the compound series, with 15·5 expansions and with 30 lbs. mean pressure, the steam consumption per indicated H.P. per hour was respectively 14·5, 15·26, and 17·07 lbs., with 400, 300, and 200 revolutions per minute.

was given by an oblique straight line (strictly an exceedingly flat curve), the total water being plotted as ordinates on a mean-pressure base; * and this he called the *theoretical* Willans law, because it had already been shown experimentally by Mr. Willans that the consumption of an actual throttling or constant-expansion engine was likewise given by an oblique straight line. The absolute steam-chest pressures required for each load can be marked on this oblique straight line, and form an equally divided scale. A number of such straight lines being drawn, Fig. 1, Plate 20, each for a different ratio of expansion, it is evident that the consumption lines for a theoretical constant-pressure engine can be obtained by joining the points showing equal pressures, as in Fig. 1, thus obtaining a series of curves.†

It will be observed that all the constant-expansion straight lines and all the constant-pressure curves pass through the origin, showing that with zero back-pressure the water consumption is nil at zero mean-pressure. Following one of the straight lines, say that for four expansions, it will be noticed that it intersects the constant-pressure curve for 100 lbs. at 55 lbs. mean pressure; at this point therefore the consumption of the constant-pressure engine is equal to that of the constant-expansion engine; and inasmuch as for lower mean pressures the curve lies below the straight line, the two being in the form of a bow with its string, the consumption of the constant-pressure engine is less at all lower points than that of the constant-expansion engine, the difference being the vertical intercept between the straight line and the curve.

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* In the remarks referred to (pages 97–8), the diagram of this theoretical constant-expansion engine was defined as follows:—the admission was at constant pressure, the expansion adiabatic, the release instantaneous, and the back-pressure absolute zero; there was no compression and no clearance; and initial condensation, radiation, and all other losses, were supposed to be nil.

† The size and speed of the engine for which these consumption lines have been worked out are such that one lb. mean pressure gives one indicated H.P.; and it is suggested to call this the "standard-consumption engine." The consumption of any other size of engine can at once be deduced thus: the weight of steam required per hour for a theoretical engine capable of indicating 1,000 H.P. with 30 lbs. mean pressure will be $1000 \div 30$ times that for the standard-consumption engine.

The consumption lines in Fig. 1, Plate 20, have been drawn on the assumption that the back pressure is absolute zero; but if the back pressure is B lbs. per square inch, the only effect is to reduce the readings of the mean pressure by B lbs., as explained in the author's remarks above referred to; and these consumption lines can therefore be applied easily to any back pressure, by shifting the mean-pressure scale bodily to the right to the extent of the back pressure. Thus if the back pressure is 3 lbs. absolute, the consumption at 0 lbs. mean pressure will be the same as it is with 3 lbs. mean pressure when the back pressure is 0, and will therefore no longer be nil as above; and at 30 lbs. mean pressure with 3 lbs. back pressure the consumption will be the same as it is with 33 lbs. mean pressure when the back pressure is 0; and so on,* as is shown by the second scale of mean pressures in Fig. 2. The latter is an abstract from Fig. 1, and compares the consumption at all loads of a theoretical constant-expansion engine, and of a theoretical constant-pressure engine, in three cases: namely when the expansions are 2, 6, and 14 times, and the initial pressure is 50, 100, and 200 lbs. absolute per square inch respectively. It will be seen that at all loads less than full load the theoretical gain in economy by expansion governing is very considerable for a low initial pressure, but rapidly diminishes as this pressure increases. Thus at a mean pressure of 20 lbs. the gain by expansion governing, when the initial pressure is 50 lbs., is 42·5 per cent.; at 100 lbs. initial pressure it is 26·3 per cent.; and at 200 lbs. it is 18·2 per cent. This diminution in the economical advantage of expansion governing is confirmed by experiment. Fig. 3, Plate 21, gives in full lines the actual consumption lines for a Willans condensing engine when working with low initial pressure, and Fig. 4 when working with high initial pressure; and it will be seen that at 20 lbs. mean pressure the actual gain by expansion governing is 10·5 per cent. with the lower initial pressure, and only 5·4 per cent. with the higher. The corresponding theoretical

* This statement applies to a theoretical engine only, and the data at the author's disposal show that it is nearly true for actual compound engines with cylinder ratio of 1 to 2; but that it is doubtful whether it is true for other cylinder ratios.

consumption lines deduced from Fig. 2 have been plotted for comparison in dotted lines, and two important differences are at once evident: first, the proportional gain in economy by expansion governing is greatly less in the actual engine than it is in the theoretical; and secondly, in the actual engine the constant-pressure or variable-expansion curve cuts the Willans or throttling line at 9 lbs. mean pressure in Fig. 3 and at 14 lbs. in Fig. 4, showing that with light loads the throttling engine is the more economical of the two. The economical gain by expansion governing is therefore considerably less than would appear at first sight from theoretical considerations, the obvious reason being that the higher steam-chest pressure increases the losses due to initial condensation, to radiation, and to leakage—these losses making themselves felt more and more as the pressure increases.

Returning to Fig. 3, Plate 21, which gives the lines of water consumption in an actual simple engine when condensing and working with an available steam-pressure of only 60 lbs. absolute, it will be noticed that the throttling engine is arranged for a maximum load corresponding to 35 lbs. mean pressure; and under these circumstances, as already pointed out, expansion governing is more economical than throttle governing to the extent of 10·5 per cent. at three-fifths load. This is the case referred to by Mr. Willans in page 42 of his paper on Steam-Engine Trials (Proceedings Inst. C.E., 1893, vol. cxiv); and in his opinion to such cases as this is largely due the fashion of considering that expansion governing is necessarily much more economical than throttling. Variable-expansion gear was first applied to simple engines working with low boiler-pressure and often with still lower steam-chest pressure. For enabling an occasional heavy load to be dealt with, such engines had originally been arranged to cut off much later than was required for ordinary work. Naturally the change gave excellent results; and it was too often assumed that the application of variable-expansion gear would produce an equal saving in cases which were altogether different. Even in the case just considered, by no means would the same saving be effected if the throttling engine were not adjusted for working at an excessive load, such as 35 lbs. mean pressure is, relatively to 60 lbs. initial pressure. Had the engine

been arranged to work at only 25 lbs. mean pressure as its maximum load, and therefore with the advantage of greater expansion at all times, the economy to be obtained by varying the expansion in place of throttling would have been much smaller, as is shown in Fig. 3 by the line marked W.

It is most unlikely however that a new engine would be constructed to work with so low a pressure as 60 lbs. absolute. Fig. 5, Plate 22, refers* to a more usual case, namely that of a compound condensing engine working with a fairly high boiler-pressure. It is assumed that 150 lbs. absolute is the maximum pressure available at the engine; and that the engine is so designed as regards strength and bearing surfaces that it will run continuously with 40 lbs. mean pressure, and for short periods with 50 lbs. mean pressure. In Fig. 4 the throttling engine is arranged for ten expansions; which with 150 lbs. absolute initial pressure limits the mean pressure to 36 lbs. as a maximum, whereas with variable cut-off there is no difficulty in obtaining 50 lbs. mean pressure. If however the conditions of working require 50 lbs. mean pressure for short periods, then to obtain this with throttle governing the fixed cut-off must be made later, and the consumption will be increased for all loads, as shown in Fig. 5 by the straight line W_1. If on the other hand it is certain that the load on the engine will never exceed that corresponding with 32 lbs. mean pressure, then the cut-off can be made earlier to correspond with this load; and the resulting consumption line for throttle governing, marked W_2 in Fig. 5, is much closer to the variable-expansion curve than in either of the two previous cases, in fact so close that advantage from the use of variable-expansion gear must be sought upon other grounds than that of economy. It will be noticed that in this case at all loads below half load the variable-expansion engine actually uses more steam per horse-power than the throttling engine.

The above points to the following method for constructing a diagram, by means of which the economy of governing by variable

* In Fig. 5 the actual variable-expansion consumption-curve shown in Fig. 4 is reproduced; and also the throttling consumption-line for ten expansions. marked W.

expansion and by throttling can be compared. Draw the water-consumption curve PP for variable expansion, Fig. 6, Plate 22, suitable for the case under consideration: that is to say, according as the engine is condensing or non-condensing, simple, compound, or triple. Then draw a vertical line MP through the maximum mean-pressure at which under any conditions the engine may have to work; and through the intersection of this vertical with the variable-expansion curve draw the throttling straight line PE, according to the Willans law. The required comparison is thus established.

A most important point to notice is that with throttle-governing the water per I.H.P. decreases continually as the load increases; but with expansion-governing the water per I.H.P. decreases at first with increase of load, until the best economy per I.H.P. is reached, after which it increases. This can be shown in the following manner. Let the curve *Pp*, Fig. 7, Plate 23, be the water-consumption curve for constant pressure *P*; then in order to find the consumption per I.H.P. corresponding with any point *p* on the curve, draw a straight line *Op* to intersect the vertical scale * marked "water per I.H.P."; the point of intersection *d* shows the water per I.H.P. at the point *p*, namely 16·8 lbs. in the example taken. It is evident that, in order to find the mean pressure corresponding with the minimum consumption per I.H.P., it is only necessary to draw a tangent *OT* to the curve from the point *O*; then a vertical *Tm* through the point of contact gives the corresponding mean pressure. It will also be seen that, as the point *p* moves to the right along the variable-expansion curve, the water per I.H.P. represented by *Id* will diminish until the point *T* is reached; beyond this point the consumption per I.H.P. increases until the point *P* is reached, beyond which it will be supposed the engine is not intended to work. *PE* is the consumption line for a throttling engine: in this case it is clear that the minimum consumption occurs at *P*.

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* The water per I.H.P is evidently proportional to $pn \div On$, that is, to the tangent of the angle pOn, which is proportional to Id; so that the scale of "water per I.H.P." is evidently an equally divided vertical scale; and it is convenient to place it at 10 lbs. mean pressure, as it is then one-tenth of the scale for total feed-water.

This construction readily solves the following important problem, which is given here although only indirectly connected with the present enquiry. The problem is: what is the most economical mean pressure to work at, knowing the conditions of loading, the kind of engine, and the available steam-pressure. For instance, let a compound condensing engine, with an available steam-pressure of 150 lbs. absolute per square inch, be required to work principally at a load of 300 I.H.P. but occasionally up to a maximum of 600 I.H.P.* The variable-expansion consumption-curve for 150 lbs. is given in Fig. 7, Plate 23; and, as already seen, the lowest consumption per I.H.P. is obtained with 30 lbs. mean pressure, and is 14·8 lbs. of water per I.H.P. per hour. Since the engine is working most of the time in the neighbourhood of 300 I.H.P., the cylinders ought if possible to be so arranged as to give 300 I.H.P. with 30 lbs. mean pressure; but with such cylinders the mean pressure required for the maximum load of 600 I.H.P. would be 60 lbs., which cannot be obtained with the steam-pressure available in a compound engine with the usual ratio of cylinders. There would be no difficulty however in obtaining 50 lbs. mean pressure; hence an increase of cylinder volume is necessary in the ratio of 50 to 60. With the enlarged cylinders 300 I.H.P. would require $30 \times 50 \div 60 = 25$ lbs. mean pressure per square inch. Referring to Fig. 7 it will be seen that with this mean pressure the consumption per I.H.P. is 14·9 lbs., or an increase of only 0·1 lb. over the minimum.

To take another example, let the average load be 450 I.H.P. and the possible maximum 600, the other conditions being as before. In this case the cylinders ought to be arranged to give 450 I.H.P. with 30 lbs. mean pressure; and thus the mean pressure required for the 600 I.H.P. would be $30 \times 600 \div 450 = 40$ lbs.

The true criterion of the engine's performance ought however to be the water consumption per brake H.P., and not per indicated H.P. With a slight modification of the above construction, the mean pressure can be determined which gives the best economical results

* Such a case is not unlikely to occur in electric tramway work and in rolling mills.

per brake H.P.; such a question however does not enter into the scope of this paper.

From the foregoing it appears that, at any rate up to a certain point, the lower the mean pressure for which the fixed cut-off is arranged, the less difference is there between the consumption with throttling and the consumption with variable expansion. For a particular number of expansions however the Willans straight line is a tangent to the variable-expansion curve; and for all mean pressures below the point of contact the throttling engine is more economical than the variable-expansion engine. The best possible results would therefore be obtained by altering the cut-off from full load down to a certain mean pressure depending on the conditions of the case; and from this mean pressure downwards by reducing the power of the engine by throttling. A case in point is illustrated in Fig. 23, Plate 28. From A to B the cut-off is varied, and the saving effected in comparison with a constant cut-off is exhibited by the difference between the curve and the Willans straight line W_3. At B the cut-off becomes fixed, and the consumption then follows the Willans line W_4; and the saving is the difference between this line and the dotted portion of the variable-expansion curve. This result can be obtained by an arrangement consisting essentially of a throttle-valve governor, together with a steam cylinder and piston which controls the cut-off. The movement of the piston is produced by the changes of pressure in the steam-chest, which are caused by the throttle-valve. Such an arrangement can be applied to any engine; but the exact mechanism will of course depend on the class of engine with which it is used.

Thus far condensing engines only have been considered; but Fig. 8, Plate 23, gives the lines of water consumption for a non-condensing engine with variable expansion, and also with throttling. The available pressure at the engine is 150 lbs. absolute; and by way of comparison the consumption lines for a condensing engine with the same available pressure have been drawn. The important point to observe is that the economical mean pressure is considerably greater for a non-condensing than for a condensing engine. Thus in the example chosen, the lowest consumption with the non-condensing

engine occurs with 45 lbs. mean pressure, and is 20·5 lbs. per I.H.P.; whereas with the condensing engine it occurs with 29 lbs. mean pressure, and is 14·8 lbs. per I.H.P., as is seen by drawing tangents from the origin to the respective consumption-curves. In fact the economical mean pressure in a non-condensing engine is nearly equal to the greatest mean pressure that can be obtained in it, supposing it to be a compound engine with the usual ratio between the cylinders; but in a condensing engine it is not much more than half the greatest mean pressure which can be obtained. This difference is of great importance, and materially reduces the value of variable cut-off gear in non-condensing engines. As an illustration the case may be taken where the engine is occasionally, but for short periods only, called upon to develop the greatest possible power compatible with the steam-pressure available. Inasmuch as under these conditions the major portion of the work is done at the economical load, it will be sufficient to compare the water consumption of the engines at their respective economical loads: that is at 45 lbs. mean pressure for the non-condensing engine, and at 29 lbs. for the condensing engine. Fig. 8 gives the consumption lines; and it will be seen that in the non-condensing engine the water per I.H.P. per hour is 22·2 lbs. for the throttling engine, and 20·5 lbs. for the variable-expansion engine, or a gain of 7·6 per cent. by variable expansion. In the condensing engine the corresponding figures are 17·2 and 14·8 lbs. per I.H.P. per hour, showing a saving of 14 per cent. in favour of the variable-expansion engine.

Governing.—It would appear that Corliss, Sulzer, and other similar trip-gears can be made to work up to speeds of about 150 revolutions per minute. Taking the valve motion into consideration, such gears are mechanically as simple as throttle-valve gear; and the working parts of the governor require little power to move them, so that such governors are very sensitive. For a simple engine therefore the two methods ought to be on a par in respect to closeness of governing, but with some advantage to the expansion governor on account of the generally smaller clearance, and the absence of the reserve of steam which is contained in the steam-chest of the throttling engine

and is consequently beyond the control of the governor. For a compound engine however the trip gear has clearly the advantage, as it can be more readily applied to each cylinder; and this is still more true of a triple-expansion engine. Up to 150 revolutions per minute therefore throttle-valve governing need not be considered.

Above these speeds however, variable-expansion gears, being no longer of the trip class, require considerable power to work them as a rule; and it is usual to employ powerful shaft-governors for the purpose. Such governors are clearly more expensive than throttle-valve governors, and are probably also less sensitive. The comparative simplicity of throttle-valve governors, and their greater sensitiveness under such circumstances, are in fact their great recommendation.

The object in view in regulating the speed of an engine is to approximate as nearly as possible to an absolutely uniform angular velocity. Irregularities in this respect may occur as follows:—(1) variation during a single revolution; (2) variation without change of load, or with only slight change of load or steam pressure; (3) variation consequent on considerable but gradual change of load or pressure; (4) momentary variation consequent on sudden change of load. For a given engine, changes in angular velocity during a single revolution depend solely on the fly-wheel and not on the governor: excepting indeed in an exceedingly slow-speed engine, where the governor may have some effect. Accuracy in this respect is evidently attained more easily in a high-speed engine than in a slow-speed engine. The second class of variation is generally due to friction in the governor, or rather to want of power in the governor to overcome the friction: so that a considerable change in speed is required to move the governor, and to effect any change in the position either of the throttle-valve or of the cut-off. Expansion gear driven by a shaft governor is clearly more difficult to manage in this respect than a throttle governor. The third variation can be reduced, whatever the kind of governor, to any percentage desired, however small; but the penalty paid for extreme accuracy in this respect is liability to

"hunt," unless accuracy is obtained by a secondary governor or by means of secondary action in the governor. As regards hunting, it would appear that high-speed engines, especially if governed by the throttle-valve, are more liable to this defect than slow-speed engines. A rapid oscillatory motion of the valve can produce only a small effect in a slow-speed engine, because the inertia of the parts and of the fly-wheel is so considerable as to prevent any great proportionate change in speed during the interval of an oscillation. A high-speed engine however, owing to the much reduced inertia, responds to any alteration in the position of the valve by changing its speed materially; or in other words the speed of a high-speed engine tends to follow the oscillations of the throttle-valve. Such oscillations are produced by any stickiness in the governor, and are much increased in amplitude if the time of oscillation of the governor synchronizes with the revolutions or with some multiple of the revolutions of the engine, or in exceptional cases with the oscillations of the steam in the steam pipes. It would appear that in this respect expansion-governing is less liable to "hunting": which may be due to the governing action occurring intermittently, that is, when the cut-off takes place; whereas the throttle-valve is governing more or less continuously.

The fourth requirement of governing, namely capability of dealing with momentary sudden and considerable changes of load, does not apply to all engines, but only to those in which the load actually changes in this manner: such for instance as an engine driving a wire mill. Rapidity of action of the governor is essential in this case; but a heavy fly-wheel is also necessary, in order to secure fairly steady running, and it is evident that, theoretically at any rate, the momentary change of speed can be reduced to any desired percentage by suitably increasing the weight of the fly-wheel. The momentary change in speed in an engine on suddenly changing the load is looked upon by many as the best criterion for comparing the relative merits of the governing of engines. It is no doubt a good test, if not pushed to extremes; but it should be observed that the governing arrangements of an engine may be perfectly suitable for a slowly changing load, and yet quite unable to cope

with a suddenly changing load. The highest perfection of governing when dealing with a suddenly changing load can be obtained only by having an abnormally heavy fly-wheel, and by regulating the admission of steam to each cylinder individually in compound and triple-expansion engines. The latter regulation generally involves a considerable addition of gear to the engine, and the brake efficiency is proportionately reduced.

In order to compare the relative merits of expansion and throttle governing in respect to a rapidly changing load, the author will consider three different high-speed engines of the same kind and power, the first being simple, and the other two compound and triple, with receivers and with the cylinders arranged tandem-fashion; and it is further to be understood that each engine is running at the same speed, and has the same fly-wheel power.

In a simple engine, when governed by the throttle, a sudden increase of load is met by an increase of pressure; and if the governor is sensitive, the interval between the change of load and the increase of pressure is exceedingly short, so that the speed will be well maintained. If, on the other hand, the engine is governed by the cut-off, the heavier moving parts of the governor, if of the fly-wheel kind, will increase the interval between the change of load and the action of the governor: so that the speed of the engine will drop more than in the former case. But inasmuch as the first effect will be to make the cut-off too late, the engine will momentarily develop considerably more horse-power than the normal, owing to which the normal speed will be recovered in less time than with a throttle governor; it may however overshoot the mark, and thus oscillations in the speed may take place for a short time. If the load is suddenly diminished, the throttle-valve governor will act more rapidly than the expansion governor; but on the other hand there is the steam in the steam-chest to deal with. Both arrangements are capable of cutting off the whole steam-supply from the engine; hence the recovery to normal speed will occupy practically the same time in both. It appears therefore that in a simple engine the regulation when dealing with suddenly changing loads is on the

whole as good with a throttle governor as with an expansion governor.

In a compound engine with receiver, when the load is suddenly increased, the receiver has to be filled to the pressure corresponding with the increased load before the low-pressure cylinder can do its fair share of the work; and the increase of the load may be so considerable that, even with the admission of the full boiler-pressure, the power developed in the high-pressure cylinder may, if the engine is governed by the throttle-valve, be insufficient to make up the difference, as is illustrated in Figs. 9 to 12, Plate 24; and this loss of time will cause a considerably greater reduction in speed than in a simple engine. If however the engine is governed by the expansion, the cut-off in the high-pressure cylinder will become later than is necessary for the load: so that not only will this cylinder do more than its fair share at first, but, what is equally important, the receiver will also be more rapidly filled, thus enabling the low-pressure cylinder sooner to do its proper share, as shown in Figs. 13 to 16. Clearly therefore the reduction of speed will be less than with throttling. When however the increase of load is comparatively small, the greater sensibility of the throttle governor will cause less reduction in speed. It is evident therefore that there is some particular increase of load, which is equally well dealt with by either form of governor, so far as regards reduction in speed; and that for a smaller increase the throttle valve has the advantage, for a greater increase the expansion governor.

The effect of suddenly and largely diminishing the load on a compound engine with receiver, if governed by the throttle valve, would be nearly to shut off the steam supply altogether; the speed however would still increase for a time, owing to the steam already in the receiver and in the steam-chest. On the other hand, if the engine is governed by the cut-off, the steam supply to the high-pressure cylinder is at once entirely cut off, should the diminution of load be so great as to need this, no matter what the pressure in the steam-chest may be; and thus only the steam in the receiver has to be dealt with. Unless therefore the governor acting on the throttle valve is far more sensitive than that acting on the expansion, the speed

of the engine will momentarily rise more in the former case than in the latter. The same arguments apply to a triple-expansion engine with receivers, the effect of the second receiver being added; and it is clear therefore that the change of speed produced by an equal sudden change of load will be greater in such an engine than in a two-cylinder compound engine with receiver; and this will be the case whether the engine is governed by the throttle or by the expansion.

In certain special instances advantage in the way of economy can be obtained by materially reducing the speed of the engine as the load is diminished. To effect this the adjustment of the governor must be made whilst the engine is running. This can be done with comparative ease with a throttle-valve governor; but the powerful shaft governors, required as a rule for expansion governing in high-speed engines, are more difficult to adjust whilst running, although there are arrangements for doing this.

Having compared in a general way the relative effects of expansion and throttle governing on the economy and closeness of governing of an engine, the author now purposes applying the results of this comparison to a few typical cases which occur in practice. Reviewing what has been said, it will be seen that the nature of the load is the most important factor in deciding whether the engine should be governed by the throttle or by the cut-off; and if the conditions are such that the most economical load of the engine ought to be less than the full load, or that the engine has to be overloaded for short periods of time, or that the load is subject to sudden and considerable fluctuations, under any such conditions it is better that the governor should act on the cut-off.

Electric-Light Engines.—In a well designed central station there will be a number of engines principally of one size, and a few smaller engines. The fluctuations of load, although rapid at times, are approximately known beforehand, because they follow with more or less accuracy a previously ascertained load-curve. It is therefore possible at all times so to work the engines that the load on those running is approximately their economical load. Under these

conditions expansion governing has no advantages, if the engines are working non-condensing; because in this case, as already pointed out in reference to Fig. 8, Plate 23, the economical load is obtained with so high a mean pressure that, except with unusually high boiler-pressures, the highest mean pressure that can be obtained gives the best economy. If however the engines are condensing, the conditions are considerably changed; because, as already seen, the economical load is now obtained with a much lower mean pressure than the possible maximum, namely from 28 to 32 lbs. according to the boiler pressure available. Supposing that the engines are mechanically designed to be able to run continuously with 50 lbs. mean pressure, it is then possible to run them at powers materially greater than their economical load; and this tends to economy, because on a rising load fresh engines can be started later and with more deliberation, and on a falling load superfluous engines can be stopped sooner. In order to work the engines in this manner—that is, with best economy at 28 to 32 lbs. mean pressure and with power to overload—it is obviously necessary to be able to alter the cut-off. Hand gear would in this instance answer the purpose; but automatic-expansion gear is undoubtedly preferable.

In order to obtain some idea of the economical gain of expansion-governing under such circumstances, the following example has been worked out. The load-curve chosen is that for twenty-four hours at the Kensington Court electric-light station on 2nd December 1890, which was first published by Mr. Crompton in his paper read before the Institution of Civil Engineers on 7th April 1891 (Proceedings, vol. cvi, page 7), and which has done duty many times since. It is assumed that each of the principal engines in the station is capable of developing 140 electric H.P. with 40 lbs. mean pressure in the cylinders; and that there are two smaller engines, each capable of developing 70 electric H.P. with the same mean pressure: these are somewhat larger units than those actually in the station. It is also supposed that the pressure available at the engines is 150 lbs. absolute per square inch.

Fig. 17, Plate 25, shows the times at which the different engines would be started and stopped when the governing is done by the

throttle, the cut-off being arranged for a mean pressure of 34 lbs. per square inch; and from this, with the help of the throttle-governing steam-consumption straight line given in Fig. 5, Plate 22, the water required to be evaporated for the engines only can be calculated, and is found to be 110,330 lbs. for the twenty-four hours.

Fig. 18, Plate 26, shows the effect on the times of starting and stopping when the engines are governed by the cut-off, and are allowed to be overloaded up to 50 lbs. mean pressure, assuming that the dynamos are designed to stand this overload. As before, the total water required in twenty-four hours can be calculated with the help of the variable-expansion consumption curve given in Fig. 5, Plate 22, and it works out to 102,100 lbs.

In the particular instance here chosen it will be seen that at the time of maximum load four units are running with expansion governing, Fig. 18, as against six and a half with throttling, Fig. 17. This points to the fact that expansion governing tends to reduce the number of engines required in an electric-light central station; in other words, it can better be afforded to overload engines with expansion governing than engines with throttle governing, for in the former event the economical ill effects of the overload are temporary, while in the latter they are permanent. On the whole therefore it can be stated that for large central electric-light stations, when working non-condensing, throttling is as good as expansion governing; but when condensing, governing by the cut-off has a superiority.

An electric-light station containing only one engine will evidently be worked most economically by altering the cut-off, if the engine is condensing. If the engine is non-condensing, the case is not so clear. A great deal depends on the boiler pressure that can be obtained; and it will be observed that the power of overloading the engine is not of much advantage, because in all probability the time of overload would last too long to be permissible, unless there were a peak in the load curve, as shown by the dotted line in Fig. 22, Plate 28: in which case of course expansion gear would be of use. Thus one of the factors determining the relative merits of the two methods of governing, as applied to this particular kind of work, is the shape of the load curve; but as

it is impossible to know beforehand what the shape will be, it is best in practice to arrange the engine with expansion gear, because this will meet all cases, whereas throttle gear will not. In electric-light stations of medium magnitude, containing say three or four engines, throttle governing will give as good results as expansion governing if working non-condensing; if condensing, expansion governing will be best.

Dynamo Engines for Transmission of Power.—Many different cases occur, depending on the number of motors and on the kind of work to be done; and the differences will be expressed by the shape of the load curve. When there are many small motors, which are not frequently started and stopped, changes in load will take place gradually; the load curve will be fairly regular, and in shape not unlike that for electric-light stations: evidently then the same remarks apply.

A somewhat unusual case and difficult to deal with is that of a single shunt-wound motor driven by a single shunt-wound dynamo, the latter in its turn driven by a single engine. The first difficulty is met with on starting the motor, especially if it has to start with even a small load on it. The torque or turning moment required for starting is great; and if the engine is governed by the throttle, the maximum torque which the engine can give out is reached sooner than if the engine is governed by the cut-off; because the latter allows of momentary excessive overload. The second difficulty occurs whilst the machinery is running, should the load fluctuate considerably in the neighbourhood of the full load. If the engine is governed by the throttle, directly the full load is overstepped the speed of the engine must drop; the available horse-power will thus be diminished, and if the load remains only for a short time above the full load, it must inevitably pull up the engine: or rather it would do so, were it not that the fuzes in the circuit would blow, owing to the abnormal increase in the current due to the reduction of counter electromotive force in the motor. If, on the other hand, the engine is governed by the cut-off, the overload on the motor will be met by an overload on the engine, and the

difficulty will disappear. This is evidently a case where expansion governing is far preferable to throttling, and in fact may be said to be necessary: although throttle governing could be made to answer, by fixing the cut-off late enough; but then the economy of working would be greatly reduced.

Electric Tramways and Railways.—The most important case however is that of electric tramways and railways. A glance at the typical load-curves illustrated in Figs. 19 to 21, Plate 27, will show that the machinery cannot be worked like that of an electric-light station; that in fact all the engines, except the spare ones standing in reserve, must be kept running; and that they are alternately fully loaded and lightly loaded at short intervals of time. The power of being able to overload the engines for a short time, as can be done with expansion governing, is here of the utmost importance, especially from the economical point of view; and there is the incidental advantage, as previously explained, that expansion gear responds more readily to sudden changes of load. This being so important a case, it may be well to illustrate it by a numerical example. Figs. 19, 20, and 21 are typical load-curves for ten minutes on an electric railway; and it will be noticed that in each of the three figures a peak of the same height is shown at A, so that the same number of engines have to be worked in each instance. It is proposed to calculate the water required to be evaporated for the engines during each ten minutes under the following five different conditions:—(1) the engines are governed by the throttle-valve with the cut-off arranged for 35 lbs. mean pressure, when the full available pressure is used; (2) the engines are governed by the throttle-valve with the cut-off arranged for 45 lbs. mean pressure, when the full available pressure is used; (3) the engines are governed by the throttle-valve with the cut-off arranged for 50 lbs. mean pressure, when the full available pressure is used; (4) the engines are governed by the cut-off; (5) the engines are governed by the cut-off from 20 lbs. mean pressure upwards, and by the throttle-valve from the same mean pressure downwards (see page 163).

In Fig. 19, Plate 27, there are three peaks of nearly the same height as A, and the engines are comparatively well loaded during the whole ten minutes. In Fig. 20 the other peaks are of medium height; and this figure represents a medium load on the engines. Lastly Fig. 21 denotes only a light load on the engines. It will be supposed that each engine is capable of developing 980 I.H.P. at 35 lbs. mean pressure, 1,260 I.H.P. at 45 lbs., and 1,400 I.H.P. at 50 lbs. mean pressure; further that the engines are condensing, and that the full available pressure is 150 lbs. absolute; it will then be possible to use the consumption curve given in Fig. 5, Plate 22, which has been reproduced in Fig. 23, Plate 28.

In the first case—throttle governing with the cut-off arranged for a maximum of 35 lbs. mean pressure—it is necessary to keep six engines running; and since they are working with constant cut-off, the consumption at all loads will be represented by a straight line, and therefore the total actual consumption will be the same as if the engines were working under a constant load equal to the average load.* For the ten minutes shown in Fig. 19, Plate 27, the average load is found to be 3,116 I.H.P.; hence the average mean pressure is $35 \times 3{,}116 \div (6 \times 980) = 18{\cdot}55$ lbs. per square inch. Referring to Fig. 23, Plate 28, it will be seen from the Willans line W_1 that the water consumption of the standard-consumption engine at this mean pressure is 312 lbs. per hour; hence the total consumption for the ten minutes is $(312 \div 6) \times 6 \times 980 \div 35 =$ 8,740 lbs. The water consumption for Figs. 20 and 21 can be found in exactly the same way; and the result is given in Table 1 (page 175).

In the second case—throttle governing with the cut-off arranged for 45 lbs. mean pressure—it is found that this increase in the available power of each engine allows of stopping one engine, keeping only five running. The consumption of each engine is now represented by the Willans line W_2 in Fig. 23, Plate 28, and is

* This result follows at once from the Willans straight-line law; and moreover the author obtained an experimental proof, as mentioned in his remarks upon Dr. Edward Hopkinson's paper on the City and South London Electric Railway (Proceedings Inst. C.E., 1893, vol. cxii, page 263).

TABLE 1.—*Electric Tramways and Railways.*

Water Consumption during ten minutes.

Plate 27.	Fig. 19.				Fig. 20.				Fig. 21.				Unit Sets of Engines and Dynamos required.
Maximum Electrical H.P. in each case 4,634.	Average Electrical H.P. 2,117.				Average Electrical H.P. 1,527.				Average Electrical H.P. 750.				
Conditions of Governing.	Indicated H. P.		Water Consumption.		Indicated H.P.		Water Consumption.		Indicated H.P.		Water Consumption.		
	Maximum.	Average.	Total.	Increase.*	Maximum.	Average.	Total.	Increase.*	Maximum.	Average.	Total.	Increase.*	
	I.H.P.	I.H.P.	Lbs.	p. c.	I.H.P.	I.H.P.	Lbs.	p. c.	I.H.P.	I.H.P.	Lbs.	p. c.	Units.
Cut-off fixed for 35 lbs. mean pressure	5,633	3,116	8,740	22·1	5,633	2,526	7,490	28·4	5,633	1,749	5,830	38·2	6
„ „ „ 45 „ „ „	5,466	2,950	8,590	19·9	5,466	2,359	7,150	22·6	5,466	1,582	5,300	25·8	5
„ „ „ 50 „ „ „	5,300	2,783	8,250	15·2	5,300	2,193	6,730	15·4	5,300	1,416	4,750	12·7	4
Variable Cut-off	5,300	2,783	7,220	0·8	5,300	2,193	5,895	1·1	5,300	1,416	4,560	8·2	4
Variable and Fixed Cut-off . .	5,300	2,783	7,160	0·0	5,300	2,193	5,830	0·0	5,300	1,416	4,215	0·0	4

* The figures in these columns are the percentage increase in water consumption compared with the fifth arrangement.

greater than in the first case; nevertheless the total consumption is less than in the first case, as shown in Table 1.

In the third case—throttle governing with the cut-off arranged for a maximum of 50 lbs. mean pressure—only four engines are required, because they can now develop for short periods a sufficient power; but as the cut-off must be later, the consumption at all loads will be greater, as shown by the Willans line marked W_3 in Fig. 23, Plate 28. The average I.H.P. however is smaller, because the losses in the dynamo and engine of the fifth and sixth set are saved. The average thus becomes 2,783 I.H.P; and the total water-consumption for the ten minutes comes out to 8,250 lbs. for Fig. 19, Plate 27.

In the fourth case—expansion governing—the consumption for the short-period heavy load will evidently be the same as in the third case, as seen from Fig. 5, Plate 22; but owing to the cut-off being altered, considerable economy is obtained at the lighter loads, at which the engines do most of their work. The total water cannot in this case be obtained from the average mean pressure, because the consumption line is no longer a straight line, but has to be ascertained from the consumption for each element of the load. The result is 7,220 lbs. for the ten minutes for Fig. 19, Plate 27, as given in Table 1.

In the fifth case—combined expansion governing and throttling—the consumption is given by the variable-expansion water-consumption curve down to 20 lbs. mean pressure; and for lighter loads by the Willans line marked W_4 in Fig. 23, Plate 28. The calculations are similar to those in the previous cases, and the results are given in Table 1.

A comparison of all the results obtained, Table 1, shows that the fifth arrangement is the best for all three typical load-curves. On the mere question of economy of water evaporated it will be noticed that there is perhaps not so much difference between the first three arrangements as might be expected. The third arrangement has however the great advantage that only four engines are required. The advantages of expansion governing are striking; a considerable saving in feed-water is effected, and two engines less are needed than in the first arrangement. In fact this is just the case where expansion governing might almost be said to be a necessity.

Mill Engines.—Generally speaking, a single engine only has to be considered in mills; and the load may either be almost unchanging, or changing slowly through considerable ranges, or changing rapidly, or even suddenly. Although an absolutely unchanging load is never met with in mill work, yet in cotton mills the greatest ordinary daily change probably does not exceed 10 or 12 per cent., and in flax mills 25 per cent.

The case where the load does not change more than about 12 per cent. will now be considered. If it were possible to maintain a constant steam-pressure at the engine, then the cut-off in the high-pressure cylinder could be so fixed that the engine would develop at this pressure the maximum I.H.P. required. Supposing for instance that the steam pressure at the engine is maintained constant at 150 lbs. absolute; and that the maximum load requires 34 lbs. mean pressure, so that with 12 per cent. reduction the minimum load would be obtained with 30 lbs. mean pressure: then the lines of water-consumption for a compound condensing engine will be as shown in Fig. 24, Plate 29; and at 32 lbs. mean pressure, which for the sake of argument may also be supposed to be the average load, the gain in economy, due to expansion governing, is found by reference to Fig. 24 to be 1·83 per cent. It is evident however that in practice the boiler-pressure can not be maintained constant, and that allowance ought to be made for a fall, say of 20 lbs.; and in order to meet the contingency of maximum load coming on with minimum boiler-pressure, the cut-off must be made later than above arranged for. Furthermore, if any doubt exists as to what will be the maximum load, an additional allowance must be made by fixing the cut-off still later, which will still further reduce the economy at all loads, as shown by the upper consumption line for constant cut-off in Fig. 24; and it will be noticed that this will be the water-consumption of the engine, whether the boiler-pressure be 150 or 130 lbs. or any intermediate pressure. With expansion governing however it is unnecessary to make any allowance for uncertainty in the maximum load; but the reduction of 20 lbs. in the boiler-pressure changes the consumption curve to the upper one in Fig. 24, and for a smaller reduction of pressure the consumption

will lie somewhere between these two extreme curves. In order accurately to compare the economy by the two modes of governing, it is necessary to know in what manner the boiler-pressure varies. With careful stoking and regular feed, no material fall in the pressure ought to occur except when cleaning fires; therefore the curve of average water-consumption with expansion governing ought to be much nearer the lower curve than the upper, as shown by the dotted curve in Fig. 24. Thus the consumption at 32 lbs. mean pressure, which is supposed to be the average load, is represented by AC; and it follows that in this instance the expansion gear improves the economy in the ratio of BC to AC, or 6·45 per cent.

The case of an engine working against a load which changes slowly through considerable ranges is evidently similar to that of a single electric-light engine. The arguments already adduced therefore hold good; and consequently expansion governing is the best.

For a suddenly changing load, such as that on an engine driving a cement mill or a rolling mill, expansion governing is best adapted, as in the case of engines for electric traction, and for the same reasons: amongst which not the least important is that expansion governing allows of a smaller engine being used, and there is a greater reserve of power to meet emergencies.

A special case worth considering is where condensing engines are liable for any reason to be required to work non-condensing. In order to profit by condensing, it is clear that the cut-off must be earlier than for non-condensing. This could of course be met by having hand expansion-gear with throttle governing; but it is best to govern by automatic expansion-gear.

Discussion, 1 *February* 1895.

Capt. SANKEY thought that one of the principal conclusions to be drawn from the paper was that the great advantage of expansion governing lay in being able to overload the engines: overloading being understood to mean any load in excess of the economical load of any engine. The strongest evidence on this point was given by the example of electric traction (Table 1, page 175); but even in electric lighting the effect was distinct, although in this case the engines were working most of the time near their full load. In order further to exemplify this point, he had had additional calculations made for the electric-light engines, assuming for the sake of argument that in those governed by variable expansion the cut-off was so arranged that the mean pressure could not be increased beyond 34 lbs. This put both the engines governed by variable expansion, and those governed by throttling, under identical conditions as regarded overloading. The consumption of the engines governed by throttling was represented by the straight line W in Fig. 5, Plate 22, and of those governed by expansion by the curved line in the same diagram; in each the maximum mean pressure that could be obtained was limited to 34 lbs. Under these conditions it was found that variable-expansion engines required 109,300 lbs. of water for the twenty-four hours, as against 110,330 lbs. for the throttling engines, showing a gain of a little under 1 per cent.; but it had been shown in page 171 that when the variable-expansion engines could be overloaded to 50 lbs. mean pressure, the saving was 8 per cent.; and thus it was evident that the advantage gained was due to being able to overload the engines, and that the improvement in economy at light loads, due to variable cut-off, had but a small effect.

Mr. JOHN S. RAWORTH was glad to gather from the paper that variable expansion was considered by the author to be preferable on the whole to throttling for the governing of steam engines. From the excellent diagrams originated by Mr. Willans some excellent corollaries had here been produced. Probably many engineers who were engaged in designing steam engines had already

(Mr. John S. Raworth.)
worked out their own corollaries, so that in their own practice they might rapidly and efficiently get the exact results more easily than they could from Mr. Willans' diagrams themselves. In the present paper these excellent results had been worked out under a great variety of conditions of steam consumption; and although not agreeing with the whole of the paper, he did most cordially agree with the excellent results given, and he thanked the author for them. The central ideas of the paper seemed to him to be, firstly, that the most economical engine was always governed by variable expansion: this he thought had been settled thoroughly by every one of the instances given, although in some of them the advantage of variable expansion was only slight. Secondly, variable-expansion engines were sometimes the best mechanically. Therefore the most economical engine was sometimes the best mechanically. The rest of the paper was occupied in examining the various conditions under which engines were called on to work, and comparing the disadvantages of a bad mechanism with the advantages of a good expansion. In page 165 it was said that, above a speed of about 150 revolutions per minute, "variable-expansion gears, being no longer of the trip class, require considerable power to work them as a rule; and it is usual to employ powerful shaft-governors for the purpose. Such governors are clearly more expensive than throttle-valve governors, and are probably also less sensitive. The comparative simplicity of throttle-valve governors, and their greater sensitiveness under such circumstances, are in fact their great recommendation." And at the bottom of the same page it was said that, in respect of want of power in the governor to overcome the friction of itself and of the gear it controlled, expansion gear driven by a shaft governor was clearly more difficult to manage than a throttle governor. On the comparison between the disadvantage of a bad governor in regard to sensitiveness, and the advantage of a good expansive economical engine, the whole paper seemed to him to turn. Many engineers perhaps would decide at once that in the matter of sensitiveness there was no comparison between throttle-valve governors and shaft governors. From what he had himself seen of a great many governors, the ordinary crank-shaft governors beat the

throttle-valve governors by three to one. The shaft governors were not so well known in this country, because engines were not made here to any great extent for stock; but in America they had been fully developed. As far as he had tried both classes, he had scarcely ever got a sensitiveness in the throttle-valve governor better than $2\frac{1}{2}$ to 3 per cent. variation in speed of engine. On the other hand he had found shaft governors which were so close in governing between no load and full load, that he had had to count the engine for several minutes before he could be quite sure that there was any difference at all: that is, the difference was considerably under 1 per cent. These results were not from any special experiments he had made, but from observation of the ordinary working of governors which he had bought from the best makers of each kind. An American maker of shaft governors even guaranteed that, if his engine so governed did not run at full load within one revolution per minute of its speed at no load, both governor and engine should be forfeited to the user. This seemed to him a sufficient proof that the shaft governor was better than the throttle-valve governor. From his own experience of shaft governors he considered the real difficulty consisted in designing them with accuracy to suit any given engine, without expending much time and money in experimenting; but he had put one on an 800 H.P. engine running at 150 revolutions a minute, of which the high-pressure piston-valve weighed between 3 and 4 cwts., and a test that he had made yesterday had given the following result:—at 50 ampères or 100,000 watts the speed was 148 revolutions, and at the full load of 250 ampères or 500,000 watts the speed was 146 revolutions, being a difference of only two revolutions or $1\frac{1}{3}$ per cent. In order to test what the governor could possibly do, he had gone on altering the springs until he got the speed so uniform that he could not count any difference, getting 152 revolutions per minute with a light load, and 152 with a full load, and the governor hunting all between, as was natural enough. So far therefore as concerned any doubt whether the expansion governor was going to prove mechanically as good as the throttle-valve governor, the proof appeared to him overwhelming in favour of the expansion governor.

(Mr. John S. Raworth.)
Sluggishness he considered was a question apart from that of close governing. When the load was suddenly increased or diminished, it depended upon the sluggishness of the governor how slowly or how quickly it would respond to the change in the load. It was stated in page 167 that, if the engine was governed by the cut-off, the heavier moving parts of the governor, if of the fly-wheel kind, would increase the interval between the change of load and the action of the governor: that is, the heavier moving parts of the shaft governor as compared with the throttle-valve governor. Here he imagined the author was comparing the shaft governor with the Willans throttle-valve governor, which revolved at the same speed as the shaft, as did the shaft governor also. The revolving weights in each had only their own mass to move; they were retained by the centripetal force of the springs, which for all practical purposes were without mass. Therefore the two kinds of governor seemed to him to be exactly on a level with regard to sluggishness. When any change of speed took place, with corresponding change in centrifugal force, the weight on either governor had only its own mass to put in motion; it had not to move any other piece of metal. An illustration of the opposite kind was furnished by the Porter governor, in which there were small balls acting upon a mass of iron perhaps twenty times their weight; if they attempted to fly out, they had not only to put themselves in motion, but also to move the large mass of metal besides. In the shaft governor the conditions were exactly similar to those in the throttle-valve governor; in both of them the balls had to act only upon their own mass and no other. There was one other point that would affect the apparent sluggishness of governors, which he thought was important. With a throttle-valve governor, when a light load was suddenly increased greatly and the throttle-valve was suddenly opened wide, there was at once a huge condensation in the steam-chest and cylinder, owing to the high-pressure steam having to raise the temperature of all the surfaces of the metal, which had previously been at the lower temperature corresponding with the lower pressure. In consequence of the great quantity of water thus produced, the engine was choked, and it staggered for the first

revolution or two, until it had cleared itself of the water. If there were no other reason for preferring the variable-expansion governor to the throttle-valve governor for sudden changes of load, he thought this would be amply sufficient. Shaft governors had been spoken of in the paper (page 165) as more expensive than throttle-valve governors ; they were undoubtedly so, but he believed to a less extent than was usually imagined. For an 80 I.H.P. compound engine he had found the throttle-valve governing apparatus altogether cost £9 17*s.* 8*d.* ; while for a sister engine the variable-expansion governor altogether cost £12 8*s.* 4*d.* Two or three years ago he had thought that the difference would be much greater ; but these were the actual costs, the governors of both engines having been bought separately from the engines and put on them afterwards. The conclusions at which he had arrived were therefore that variable expansion was best in economy of steam, and best also in perfection of governing, and at the same time not appreciably more costly. It thus offered two advantages together, and he considered might therefore be adopted without any hesitation whatever. In the paper indeed there seemed yet to lurk some hesitancy in arriving at this conclusion; but from his own experience for the last three or four years he was satisfied there were no drawbacks whatever to the adoption of variable-expansion governing.

Mr. J. Courthope Peache said it must be remembered that the original trials by Mr. Willans, upon which had been based the conclusions drawn in the paper as to the economic value of throttle governing, had been carried out not on a throttling engine, but on an engine without a throttle-valve and with the boiler pressure varied to suit the initial pressure which it was desired to obtain. The economic result would not vary materially he supposed from that which would be obtained where, as in practice, the boiler pressure was kept at a maximum and the steam throttled to the engine. But, as pointed out in Mr. Willans' original paper in connection with these trials (Proceedings Inst. C.E. 1888, vol. xciii, page 160), more total heat was contained in steam raised at a higher pressure and throttled to the engine than in steam raised only at the initial pressure

(Mr. J. Courthope Peache.)
which was desired in the engine. To the extent of this difference therefore the results given in the present paper would show too low a value for the throttling engine, no doubt to a small extent only; but still it would be interesting to hear from the author whether he had tried any experiment on this point, and how far, if at all, the results should be modified accordingly.

With regard to the economic value of variable expansion, the governing dealt with in the paper for compound engines with two or three cylinders appeared to have varied the cut-off in the high-pressure cylinder only; and he enquired whether the cut-off in the intermediate and low-pressure cylinders had remained at one constant point in all the trials which had been made for Mr. Willans' original paper.

Capt. Sankey replied that in all Mr. Willans' trials the cut-off had remained the same in the intermediate and low-pressure cylinders, having been varied only in the high-pressure cylinder.

Mr. Peache wished the author had brought forward as the basis of comparison a more efficient application of variable expansion. No doubt the variation of the cut-off in the high-pressure cylinder only of compound engines was doing good service at the present day; but for the large powers contemplated in the paper, and especially for the great variations in power demanded by the requirements of electric traction, it would have been an advantage, he thought, if a better form of variable-expansion gear had been taken for comparison. In present practice many stations for electric lighting and also for electric traction were being supplied with compound and triple-expansion engines of large power, in which variable-expansion gear was fitted to all the cylinders. Perhaps this was especially the case in the United States, where many triple engines, some of the marine kind and others with Corliss gear, were fitted with variable-expansion gear on all three cylinders. As far indeed as the Corliss engines were concerned, he believed the occasion of fitting variable-expansion gear to all the cylinders had arisen in America from accidents having occurred with the fly-wheels, which had burst owing to the

engines racing on suddenly losing their load, because the steam contained in the intermediate and low-pressure receivers was sufficient to cause the damage, before the cut-off, acting on the high-pressure cylinder only, could check the speed. While this appeared to him to be one good reason for applying variable cut-off gear on all the cylinders of a compound or triple condensing engine, there were also other great advantages to be gained by so doing. In the first place, greater economy resulted, because at all loads the total range of temperature was thereby kept fairly equally divided between the several cylinders. Secondly, the turning was more even, because at all loads the work was kept fairly equally divided between the several cylinders. Thirdly, the governing was improved, because the cut-off being changed simultaneously on all the cylinders brought the engine rather more under control of the governor than even a single-cylinder engine with variable-expansion gear would be. Fourthly, the maximum load which the engine was capable of exerting could be increased, because, when the cut-off became later in the high-pressure cylinder, there was no increase of back pressure from the intermediate receiver: that is, the pressure in the intermediate receiver remained practically constant, and therefore the high-pressure cylinder could take a larger volume of steam than if the intermediate-receiver pressure were to rise in consequence. In all these respects variable-expansion gear, when applied to the high-pressure cylinder only, either failed to realise or else only partially realised the benefits to be obtained from the complete application of variable expansion.

With regard to economy, in Mr. Willans' original paper on his non-condensing steam-engine trials (Proceedings Inst. C.E. 1888, vol. xciii, page 160), when speaking of variable-expansion gear applied to the high-pressure cylinder only of a compound engine, the author said:—"The equal division of temperature between the two cylinders, which is the essential feature of the compound engine, is very soon lost, the low-pressure diagram becoming smaller and smaller as the ratio of expansion becomes greater." To this might be added that, as the ratio of expansion became reduced in order to meet an increased load, the low-pressure diagram became larger and larger,

(Mr. J. Courthope Peache.)
and consequently the equal division of temperature between the two cylinders was again soon lost in the opposite direction; and not only so, but the maximum load the engine was capable of developing was limited, because of the increased back-pressure in the high-pressure cylinder. If therefore as the basis of comparison variable-expansion gear had been taken in which the cut-off was varied simultaneously in all the cylinders of a compound or triple-expansion engine, he should expect the comparison with throttle governing would have shown still more in favour of variable-expansion gear than appeared from the figures in Table 1, page 175.

There were some features in favour of throttle governing which he thought should not be lost sight of: though, as they perhaps hardly came within the scope of the paper, they had probably been omitted on that account. One was the reduction in engine friction, in wear and tear, and in lubrication, when the pressure was reduced by throttling. Also in a throttling engine, just as in one with variable cut-off in all cylinders, the work and the range of temperature could be fairly equally divided between the several cylinders under all changes of load.

Variable-expansion governing had been spoken of in page 165 of the paper as being less readily applicable to all the cylinders of a compound or triple engine than throttle governing; and it might therefore be of interest to refer to some triple-expansion and compound engines lately supplied by Messrs. Davey Paxman and Co. for the electric lighting station at Cardiff, to which they had applied the variable-expansion gear illustrated in Figs. 26 to 28, Plate 30. The engines were of the vertical inverted marine kind, and each cylinder was fitted with a slide-valve or piston-valve worked by a pair of eccentrics and an ordinary link. The weigh-shaft W of the expansion gear was connected with the piston of a small steam relay cylinder C, of which the valve was worked by the floating lever L; the steam entered at the middle of the valve, and exhausted at the ends. The lower end of the floating lever was connected with the cross-head of the relay piston, and the upper was connected through suitable links K to the governor; the small piston-valve of the relay cylinder was connected at an intermediate point to the floating lever.

By means of this differential gear the relay piston was made to follow all the motions of the governor, so that the governor itself had practically no work to do, having only to move the small valve of the relay cylinder; therefore as sensitive a governor could be employed as might be desired. In this particular instance also advantage had been taken of the differential gear to add an arrangement of a hand lever H with a pair of small helical springs SS attached to the cross-head A on the end of the piston-valve spindle, for varying the speed of the engine while running. The equal division of work between the three cylinders was illustrated by the three sets of indicator diagrams arranged vertically in Figs. 29 to 31, Plate 31, in which the vertical scales of pressure had been made proportional to the respective cylinder-capacities; and therefore the actual areas of the diagrams represented the proportion of work done in each cylinder. The three sets of diagrams, Figs. 29 to 31, were taken with the engine indicating 317, 181, and 124 horse-power respectively; and it would be seen that the areas of the diagrams in each set were fairly equal, showing a corresponding equality of work in the three cylinders. The vertical distances between the horizontal dotted lines drawn across the diagrams represented equal ranges of temperature of 69° Fahr.; from which it would be seen that the total range of 207° was fairly divided equally between the three cylinders for each load. These diagrams had really been taken before the valves had been finally set, and as a general guide for setting them. The vacuum varied considerably, owing to a temporary cause, and rather upset the symmetry of the sets. The fourth set, Fig. 32, had been taken from the engine when running light at lower pressure, with the steam stop-valve partially closed. The engine would show to better advantage with heavier loads, and would easily develop 450 I.H.P. in full gear. Later on he hoped a thorough test would be made of the engines, and that he might then be able to lay the results before this Institution.

Mr. Matthew Paul, Jun., noticed that, apart altogether from economy under the two conditions of governing, one point was brought out clearly on comparing Figs. 9 and 13 in Plate 24. In

(Mr. Matthew Paul, Jun.)

Fig. 9 with the throttle governor, the initial pressure in the high-pressure cylinder was seen to be far less than in Fig. 13, where the engine was working with variable expansion. This of course would make a considerable difference in the running of the engine; for it was well known that, in order to find out where the slack parts were in any engine, it was only necessary to run up the links and to keep the throttle-valve fully open. Though this was perhaps a comparatively unimportant point, it was still one which should enter into the consideration of the relative advantages of the two modes of governing, as affecting the wear and tear of the engines. Another point was the effect of the governing upon the vibration of the engine. It was a matter of common experience that with an early cut-off the vibration was often excessive in an engine, which under full load with a late cut-off ran steadily enough, without any vibration at all.

As to economy however, the value of the comparisons drawn by the author between throttling and expansion governing seemed to him to be somewhat vitiated by the statement made in pages 155–6 that the numerical results given in the paper were based on Mr. Willans' experiments on non-condensing and condensing engines, and that the author had been unable to obtain any other experiments sufficiently complete for his purpose. Having gone through Mr. Willans' two papers again, he had found that only in four trials * of a simple condensing engine, out of the whole series of non-condensing and condensing trials, had the engine been worked with constant expansion and throttled; and in the table of results the word "superheated" was used as descriptive of these four trials. In Mr. Willans' experiments generally the consumption per indicated horse-power was determined with varying boiler or steam-pipe pressures and varying expansions; and the results could therefore be used with perfect fairness as representing the consumption to be got by expansion governing. But as a throttle-governed engine was represented by only the four experiments just mentioned with a simple condensing engine, it seemed to him that the results of these

* Institution of Civil Engineers 1893, vol. cxiv, trials U_4 W_4 Y_4 and Z_4 in appendix III, Table I, pages 65–73. In regard to this appendix, see foot-note to page 19 of vol. cxiv.

trials generally could not be as fairly used for determining the consumption to be got with throttle governing. It had been pointed out by Mr. Willans* that the whole of the trials preceding those designated as "superheated" had been made with steam known to be not superheated; and that this was unfavourable to the throttled engine, because, if the steam were dry as it left the separator, it must after throttling be superheated when it entered the engine. This was exactly the point which had occurred to himself also; and it seemed to him therefore that, so far as the relative economy of the two methods of governing was concerned, the conclusions arrived at in the present paper could not be regarded as altogether accurate, and must be qualified by Mr. Willans' remarks. Along with other members he had read the present paper with the greatest interest, and hoped to profit by many of the facts which had been elucidated therein.

The discussion was then adjourned to the next meeting.

Adjourned Discussion, 24 *April* 1895.

Capt. SANKEY noticed that Mr. Raworth had stated in his comparison of throttle governing and variable-expansion governing (page 181) that he had scarcely ever got a sensitiveness in the throttle-valve governor better than $2\frac{1}{2}$ to 3 per cent. variation in speed of engine, but that with variable-expansion governors he had observed a variation of less than 1 per cent. He had been disposed to think that Mr. Raworth's experience with throttle governing had been unfortunate; but the reason might be that the speeds at which these observations had been made were probably under 150 revolutions per minute, and at such slow speeds throttle governors were not in the best conditions for giving accurate results. As a rule with such speeds it was necessary for throttle governors to be driven at a higher speed by means of belts,

* Institution of Civil Engineers 1893, vol. cxiv, page 43.

(Capt. Sankey.)
which in his opinion was not conducive, as a rule, to accuracy of governing. Moreover throttle governors he thought had always been looked upon as a somewhat secondary kind of governing, and consequently had not received so much attention as had been bestowed upon variable-expansion governors; in all probability therefore the throttle governors that had come under Mr. Raworth's notice were not so good as the others, either in design or in workmanship.

It had also been stated by Mr. Raworth (page 182) that when any sudden change of speed took place, with corresponding change in centrifugal force, the revolving weights in each governor had only their own mass to move. In his own opinion however there were other masses of metal to be moved, besides merely the governor balls. In the throttle-valve governor there was the throttle-valve itself to be moved, and also the valve-rod. In the variable-expansion governor there was the link motion to be moved, and sometimes also the slide-valve. But even if the masses to be moved were proportionate to the increase in centrifugal force, it was found in practice that the travel of the balls in a throttle-valve governor could be made far less than that required in a variable-expansion governor; from which it followed that the throttle-valve governor was the more sensitive, because the governor balls had a less distance to travel. That the sluggishness due to the inertia of the masses to be moved, in the variable-expansion governor, constituted a real practical difficulty when dealing with a suddenly changing load, was evident, he thought, from American practice. There, as he was informed, it had been found necessary to make use of what was called the inertia principle in order to produce those powerful shaft-governors which gave such excellent results. Upon this point he did not think it necessary to say more, as it was pretty well understood by most engineers.*

* He had since learnt that the governor of the guaranteed engine, referred to by Mr. Raworth (page 181), was designed on the inertia principle; but he had also heard that Professor Sweet's governor, which gave most excellent results, was designed on the centrifugal principle only. See "Engineering," 21 June 1895, page 807.

Attention had been drawn by Mr. Raworth (page 182) to an important objection to the use of throttle governors: namely that on a sudden increase of load the throttle-valve would be opened wide, and a huge condensation would at once take place in the steam-chest and cylinder, and the engine would thereby be choked, and would stagger for a revolution or two. This he confessed was a point he had omitted to refer to in the paper, because his own experience of throttle governing had been entirely confined to an engine in which the drainage was so perfect that such an effect had never been noticed.

A passage in Mr. Willans' paper had been referred to by Mr. Peache (pages 183–4), which went to show that the figures given in the various diagrams were slightly unfair to the throttling engine, because no account had been taken of the fact that in Mr. Willans' experiments the boiler-pressure itself had been reduced; whereas in throttle governing the boiler-pressure remained constant, while it was the governor which reduced the pressure in the engine. This undoubtedly was the case, although, as stated by Mr. Peache, the effect was but slight. In order to confirm its insignificance, he had since had some experiments made, the results of which were shown in the diagram, Fig. 25, Plate 29, whence it would be seen that the effect was so slight that it was indeed difficult to show it at all. The circles and crosses plotted along the diagonal full and dotted lines showed the experimental points, of which there were four sets; the full lines represented the consumption when the boiler-pressure itself was varied, somewhat in the same way as in Mr. Wilians' experiments; the dotted lines showed the consumption obtained with genuine throttle-governing, the boiler-pressure being maintained constant throughout; and the gain by throttling the steam, keeping the boiler-pressure constant, was shown by the small difference between the full line and the immediately adjacent dotted line. The dotted line in the upper pair represented throttling trials in which the boiler-pressure was maintained constant at about 120 lbs.; and the dotted line in the lower pair at about 90 lbs. The difference in consumption between the full and dotted lines in the top pair was only about $1\frac{1}{2}$ per cent. at the point where they were widest apart,

(Capt. Sankey.)
representing an economy of that amount in favour of the constant boiler-pressure and throttling; the difference was considerably less for the lower pair. Having also worked out the net difference theoretically, he had found that these figures were fairly confirmed: that is to say, the gain as measured in feed-water was about 2 per cent. in the former case. This agreement however was insufficient by itself, because in an actual engine the effect on the initial condensation had to be taken into account; the condensation would be reduced by the greater dryness of the steam, but would be increased by the greater range of temperature in the cylinder. It might be thought that on the whole it would be reduced; but the experiments referred to in Fig. 25 showed that, even with a considerable amount of throttling, the balance between these two opposing causes was fairly well maintained, because the actual gain by throttling was practically the same as the theoretical gain.

The same question that had been raised by Mr. Peache had also been taken up by Mr. Paul, who further went on to say (page 188) that, "as a throttle-governed engine was represented by only the four experiments just mentioned with a simple condensing engine, it seemed to him that the results of these trials generally could not be as fairly used for determining the consumption to be got with throttle governing." This might seem to imply the idea that the present paper was based, as regarded the throttle governor, on the results of only four experiments. Although he was sure this was not the meaning intended, he would point out that, not only were all the numerical examples based on eighteen trials made by Mr. Willans with the compound engine, but the results were further confirmed by some 360 consumption trials made during the last six years in the ordinary way of business. As a matter of fact, the four trials referred to by Mr. Paul had not been made use of in the present paper.

The wish had been expressed by Mr. Peache (page 184) that experiments with variable-expansion gear fitted to each cylinder of a compound engine had been brought forward for comparison. That also would have been his own wish; but, as stated in pages 155–6 of the paper, the only sufficiently complete experiments he had

een able to find were those given in Mr. Willans' paper, to which ıerefore he had had to confine himself. Whenever the results romised by Mr. Peache (page 187) from the Cardiff engines were iven, he felt satisfied that the conclusions come to in the paper would e confirmed; and he believed with Mr. Peache that the effect of ariable expansion in each cylinder would be to show a greater dvantage for variable expansion than appeared from the figures in Table 1.

Apart from economy, several other advantages had been numerated by Mr. Peache (page 185), which were to be obtained by arying the cut-off in each cylinder. In these he fully concurred, vith the exception that he would point out it was only momentarily hat a greater maximum load could thus be obtained. As soon as ever the conditions became stable, the maximum load depended only on the cut-off in the first cylinder, and on the admission and exhaust pressures; change in the cut-off in the other cylinders affected only the distribution of the power amongst the cylinders. On suddenly increasing the load, each cylinder worked, so to speak, as an independent engine; but this effect was of course only of momentary duration.

In the explanation of Fig. 17, Plate 25, given in pages 170–1, the water-consumption of 110,330 lbs. had been calculated for engines in which the cut-off had been arranged for a mean pressure of 34 lbs. per square inch. The calculation had since been worked out again for engines having the cut-off arranged for 45 lbs. mean pressure as a maximum, and the rather unexpected result came out that the economy was improved to 107,500 lbs.; that is to say, although each engine was less economical per indicated horse-power, owing to the later cut-off required in order to allow of the higher mean pressure being obtained, yet the final result was better, simply because, being able to carry more load, each engine could be started later and stopped sooner.

There were three points in the paper to which he should like to call attention, on account of their being a little out of the range of the comparison drawn between the two modes of governing. The first was the description given in pages 156–7 of

(Capt. Sankey.)

the theoretical water-consumption line for a throttling or constant-expansion engine, as shown in Fig. 1, Plate 20, and thence abstracted in Fig. 2. These straight lines had been given for the first time by himself in his remarks on Mr. Willans' paper, as mentioned in pages 156–7; but the curved lines in each diagram, showing the theoretical water-consumption for a variable-expansion or constant-pressure engine, had been added since. The second point to which he would invite attention was the method shown in Fig. 7, Plate 23, of obtaining the water-consumption per indicated H.P. from the total water-consumption line. The third point was the plotting of experiments on the steam economy of engines, upon the basis of what he had suggested should be called the "standard-consumption engine," which he had defined in the footnote on page 157 as an engine that gave one indicated H.P. for one lb. of mean pressure.

The calculations in the paper he wished to mention had been made by his assistant, Mr. Lloyd, and the diagrams had been drawn by Mr. Cater, one of his pupils; and he was glad to take this opportunity of thanking them for their share in the work.

Mr. Michael Longridge thought the paper did not afford much ground for discussion, for the author's exposition of the limits within which a constant-pressure or variable-expansion engine was more economical than a constant-expansion or throttling engine seemed to him as incontrovertible as it was elegant. Possibly however there were engineers who, though acquainted with the Willans law upon which the author's argument was mainly founded, were reluctant to accept as of general application conclusions drawn from a comparatively small number of experiments made with a special kind of engine; and in this case the opinions of those who like himself were much occupied with steam engines of the more ordinary kinds might be acceptable, even if they went no further than an expression of agreement with the author's views. His own experience had been principally with factory engines, which were double-acting and ran at a much lower number of revolutions than the engines from which the data for the paper had been obtained; yet he believed the author's conclusions generally held good. In mill

ngines the load was nearly constant, and there seemed but little oom for economy from variable expansion. Yet, on looking back ver the last fifteen years, it would be found that in almost every nstance, when alterations had been made, variable expansion had been ubstituted for throttle governing; and undoubtedly in Lancashire nd Yorkshire there was a belief that variable expansion was roductive of economy even where there was but little variation of oad. Under such conditions variable expansion he thought did not ossess any special advantages except the following:—firstly, it nabled the engine to develop the 10 or 15 per cent. additional power equired on Monday mornings and in cold weather, with cylinders f the most economical proportions for the ordinary load; and econdly, it allowed the engine-driver to run down the fires and the oiler pressure before meal hours and before stopping for the night, vithout materially interfering with the speed of the engine. These vere in his opinion the reasons why variable expansion was to be referred to constant expansion for steady loads. As to closeness of overning, he thought there was a consensus of opinion among nanufacturers that where governing by the cut-off had been ubstituted for throttle governing the turning had been improved. Ie had also had some experience of saw-mill engines, where the load vas most irregular; for such cases he had adopted a compound ngine having cylinders in the ratio of one to four, with a slide-alve or slide-valves on each cutting off at half stroke, thus giving a onstant ratio of expansion of about one to seven. While the mill vas kept well employed, he believed, and he thought the paper howed, that the constant-expansion or throttling engine was as good s the constant-pressure or variable-expansion engine, or better.

In regard to governors themselves, he was astonished that the iemens chronometric governor (Proceedings 1853, page 82 and Plate 18) was not more generally used. In Lancashire many engines ad what was called a supplemental governor; which seemed to him otally unnecessary, if the principle of the Siemens governor was dopted. The principle of the chronometric governor consisted in a ifferential arrangement of three equal friction-cones, two of which, acing each other, were cast solid on a sleeve connecting them; and

(Mr. Michael Longridge.)
the whole casting slid on a feather upon a vertical shaft driven by the engine, being raised or lowered through a small height by a pair of ordinary centrifugal balls hinged as usual upon the shaft itself. Between these two cones, and with a minute clearance from each, the third friction-cone was keyed upon a horizontal screwed spindle. On any change in speed of the engine, the governor balls pressed either the upper or the lower of the two sliding friction-cones into contact with the intervening cone, and so caused the latter to rotate in one direction or the other, thereby opening or closing the throttle valve or shifting the variable-expansion gear to the extent required. It was evident that such a governor, having nothing to do but to move itself up to the moment of the cones coming into contact, and being unchecked till then by the resistance or friction of valve gear, would respond with the utmost rapidity and exactness to any change of speed, both when rising and when falling. It was obvious that with such a motion the speed at which the expansion gear or throttle valve could be moved might be varied, according to the nature of the load to be driven, from the slowest to almost instantaneous displacement; the slow motion could be obtained by cutting a fine screw upon the horizontal spindle, and the instantaneous motion by putting an eccentric upon the spindle; the valve rod would be connected to the nut or to the eccentric strap respectively. The rate of change of speed could also be regulated in part by the relative proportions of the friction cones; or if discs were substituted for cones, by moving the disc on the horizontal spindle nearer to or further from the centres of the two discs on the governor shaft.

Mr. William Schönheyder thought the chronometric governor just described by Mr. Longridge would produce hunting. It had previously been tried he believed for turbines and other purposes, and had been found too slow in action; and the action was also too long continued.

Mr. Richard W. Allen should have supposed that in trials of engine economy more difference would have been found in the steam

consumption when the trials were made without a throttle-valve governor attached to an engine, as against those made with the governor working, inasmuch as when a throttle-valve governor was used there was a loss of steam pressure between the boiler and the piston, due to friction and throttling, which amounted in some cases to 15 per cent.; but the comparison now given by the author (page 191), and represented in Fig. 25, Plate 29, showed that such a supposition was not correct. Few engineers had had the opportunity of making such elaborate tests as the author had been able to make with regard to both kinds of governing on one identical engine. Two years ago he had himself made some tests on identical engines constructed for the government, though he had not carried them out so extensively as those described in the paper. The trials occupied a week. The engines were about 60 horse-power, and ran at 300 revolutions a minute; they were fitted with a variable-expansion governor and also with a throttle-valve governor, but no difference could be found in the working of the two. The results brought forward in the paper of course applied only to the author's engines; they might or might not apply to other engines. Each engine had its own peculiarities. The design of the cylinders varied greatly, and either governor therefore would vary greatly in its results on different engines. Recently he had tested a well-designed engine having a large receiver, in which a large surface was exposed to the steam. Progressive trials were made, the cut-off being varied from 25 to 75 per cent. of the stroke while everything else remained the same: what was gained on one side was lost on the other; the gain by expansion was attended with increased condensation, so that the ultimate result was the same.

The method of plotting the water-consumption curve in Fig. 7, Plate 23, was one that he had not seen before; and he considered the author was to be congratulated upon having introduced so convenient and easy a method of readily getting at the steam consumption of an engine per indicated horse-power per hour.

A good deal had been heard from time to time about variable-expansion governors for small engines, say up to 100 H.P.; but in the trials which had been published the time that the governor

(Mr. Richard W. Allen.)
took to come back to rest had seldom been stated. This seemed to him so material a point that he had prepared diagrams, Figs. 33 to 37, Plate 32, for the purpose of showing how important an element was the mass of the fly-wheel in connection with variable-expansion governors. These diagrams were taken from a vertical engine of 30 I.H.P. driving a dynamo, and the term "full break" denoted the sudden removal of all the load from the engine, while "small break" denoted the sudden removal of a small portion of the load. The curves were drawn by plotting the highest and lowest readings of the voltmeter immediately after the load had been removed, and counting the number of beats the governor made, and the time taken for each beat until at rest. In Fig. 33 for instance, with a heavy fly-wheel, when the full load at 65 volts was removed suddenly, the governor oscillated for thirty seconds, making three beats in that time, and finally settled at 62 volts. Under the condition of throwing off successive portions of the load, instead of the whole suddenly, the speed of the engine rose gradually, and the rise went on as more and more load was removed, until, whether by gradual reduction of load or in one operation, the cut-off gear controlled by the governor attained such a position as to admit too little steam into the cylinder for keeping up the speed necessary to maintain the full voltage; and in many cases when the engine was working light, and every minute alteration made in the valve setting had so great an influence on the speed, it was found preferable to allow a slight drop in the voltage at no load rather than allow the speed to increase. In Fig. 35, where a lighter fly-wheel was used, the three beats of the governor before it became steady took up only fifteen seconds; whilst in Fig. 37, with a still lighter fly-wheel, the balance was so good that only a single beat took place, and the governor steadied itself in five seconds. During these three tests all the other parts of the engine and governor remained the same, the fly-wheel alone being altered. Figs. 34 and 36 showed the effect produced in small breaks of load.

It was not possible in his opinion to say generally that a variable-expansion governor was the only governor suitable for an engine, because every circumstance might alter so much in different instances.

ı the large installations required for electric lighting in the navy, r example, the engines had to work with the full boiler-pressure of ; much as 200 lbs., and also with a minimum pressure of only)0 lbs.; and he did not know of any variable-expansion governor ıat would work well under those conditions. The engines were ıerefore all fitted with throttle-valve governors, in consequence of hich they had a more uniform turning moment on the shaft ıroughout each revolution, because the steam was continued at a more ıiform pressure in the cylinder throughout the stroke. Under such ›nditions he thought the throttle-valve governors were certainly ıperior to variable expansion. No doubt hunting was the greatest ıemy of throttle governing; but he believed an engine could really e governed by the throttle-valve within one per cent. of variation ıd without any hunting at all, by adopting a novel method which ad lately been introduced, of adding on the governor spindle a oating fly-wheel, revolving loose on the spindle, and only attached › one of the governor weights. This wheel seemed to anticipate ıe action of the weights, and had in addition a great steadying effect pon the governor when any change of load took place; consequently he weights kept the same speed at no load as at full load. In many ıstances this was a highly important property.

Mr. Bryan Donkin, Member of Council, should have been glad to ee a summary of the paper, if possible, as to the best way of ;overning, whether by throttling or by altering the expansion. It ras rather a complicated and difficult subject; and the conclusions ıust at present necessarily be based chiefly upon the working of he Willans engine. Among the interesting curves shown in Figs. 1 o 8, Plates 20 to 23, he was particularly struck with that given in 'ig. 7, by which the water consumption per hour per indicated ıorse-power was arrived at so easily. The caution contained n page 155 of the paper—that no conclusion as to economy could ›e derived from indicator diagrams alone—was one which could ıot be too strongly insisted upon, inasmuch as condensation against he cylinder walls, which were generally colder than the steam, ›layed such an important part, amounting in some engines to 20 per

(Mr. Bryan Donkin.)
cent. and in others to as much as even 50 per cent. of the steam consumption. This was therefore a question which every engineer had to look into, as it could not be dealt with by indicator diagrams alone. The true criterion of an engine's economical performance, as pointed out in page 162, should be the water consumption per brake H.P., and not per indicated H.P. The subject of the paper had been dealt with lately before the American Society of Mechanical Engineers by Mr. Charles T. Porter in a paper entitled "Comparison of the action of a fixed cut-off and throttling regulation with that of automatic variable cut-off, on compound and triple-expansion engines;" and much had therein been said about cylinder condensation and how to prevent it. The question was, which mode of governing in a particular engine would give the least condensation for the same power. It had been carefully pointed out by Mr. Porter that a variable-expansion governor, admitting the full pressure of steam to the cylinder, required all the internal surfaces at the commencement of each stroke to be raised from the temperature of the exhaust up to that of the entering steam, thereby presenting most favourable conditions for condensation, while in addition, when the steam was cut off earlier and earlier in the stroke, the percentage of condensation gradually increased for the same reason. He therefore agreed with Mr. Porter that there was an opening for economy by employing a fixed cut-off, properly selected, and then regulating the speed by means of a throttle-valve governor; too early a cut-off was thereby avoided entirely. Although there was a theoretical gain in an early cut-off, it was quite lost if it practically increased the already considerable condensation in the cylinder. To obtain the best results with a fixed cut-off and throttling, Mr. Porter said there should be a better means of steam distribution, a more sensitive governor, smaller waste room, dry steam, and immunity from water in the cylinder on starting. A slow-acting governor, and a large capacity of steam-pipe and steam-chest between the governor and the cylinder, were bad. The governor should be as quick and as free from friction as possible, and the steam-chest should have a minimum capacity. Those were the opinions of Mr. Porter, with which he himself concurred.

Mr. DAVID JOY said that many years ago, while superintending the locomotive department of a railway, he had recorded a long series of carefully noted facts in the working of the locomotives, which might perhaps serve to illustrate the present question ; and as they were not the results of special experiments, but represented the daily and monthly working of the engines, they might be entirely relied upon. They related to the working of six or eight engines of exactly the same type, and doing exactly the same work. The speed between the stations varied from 50 to 52 miles an hour, and the fuel consumption was a little over 20 lbs. per mile. There were six drivers doing this work, the loads being nearly alike, and every condition as nearly as possible the same; the only differing element was the different method adopted by the men in working the engines. One set of men worked almost entirely upon the expansion gear, running the engines up to the highest point of expansion they could work at, often close on mid gear, and thinking that in that way they obtained the greatest economy. Another set of men worked mainly by the regulator, throttling the steam there as it left the boiler, and cutting off at a much later point of expansion. Premiums were given for saving of fuel, which kept them in a state of great tension and excitement. Every Monday morning there was a rush to see who was at the top of the coke list ; and afterwards to ascertain who won the prize at the end of three months. The two modes of working went on at the same time, and it might be surprising to hear that the results were almost identical. The men who ran on the throttle-valve or regulator, with the expansion lever three or four notches forward or towards full gear, often took the prize, in fact as often as the men who ran entirely upon expansion. The question therefore arose whether, as suggested in the paper, it might be best to run partly by expansion and partly by throttle. The conclusion he had himself arrived at, after all he had heard and all the facts he had witnessed, was that the best results, especially in electric-light engines, would be obtained by a judicious combination of the two plans.

Mr. Samuel W. Johnson, Vice-President, had come to the conclusion that there was a good deal to be said for throttle governing and also for expansion governing. With regard to the working of locomotives, he could quite confirm Mr. Joy's experience. On the Midland Railway some of his drivers were working with the regulator only, which practically represented the ordinary throttle-valve. Others were working with the expansion gear, keeping the regulator almost full open. Although he should himself prefer to use the full steam pressure and to work with the expansion gear, he did not attempt to control the men in that respect; and he had found quite as many men getting the premiums who drove by means of the regulator as those who used large expansions: so that there was something to be said on both sides. With extreme expansion in locomotives and keeping the regulator full open, there was always a tendency to more priming than when throttling the steam by means of the regulator; and it was probably on this account that many drivers liked to use the regulator and work with less expansion.

Mr. Michael Longridge asked whether there was not also some considerable difference in the blast in the two modes of working; and whether this would have much effect on the economy as measured in coal.

Mr. Johnson replied that was another of the reasons why some drivers preferred to use the regulator, and did not like too much expansion. Where there was a large blast-pipe they could afford to work the engine more expansively; but if there was any risk of being short of steam in working with a full load, they preferred not to have so much expansion.

Mr. Mark Robinson desired to refer to the remarks made by Mr. Raworth, only on the ground that they appeared to him to challenge the whole usefulness of the paper. For they seemed to him to imply that engineers in general had all along known variable expansion to be the best mode of governing; and that the whole array of experiment and theory contained in the paper was

out of place in what ought to have been nothing else than a plain recantation of error. With such a view he distinctly joined issue. The late Mr. Willans no doubt held strong opinions in favour of throttle governing, for the sufficient practical reason that for many purposes—especially those for which his engines were at that time chiefly designed, namely small engines for electric lighting—it was as suitable as variable expansion, and less complicated than the latter. The economic advantage of variable expansion he proved to be in all cases small; and his opposition to it was no doubt accentuated by a wholesome hatred of pretensions which could not be substantiated. It was true that no more important practical step had ever been taken in the progress of the steam engine than the introduction of variable expansion; but the exaggerated claims set up by its advocates a few years ago had been a positive hindrance to progress. The superior results attributed to its adoption were no doubt real enough in comparison with earlier engines, but they were due only in part to the variable expansion; the engines themselves were improved all round, and the same improvements applied to throttling engines would have altered the comparison completely. Mr. Willans had applied those improvements to throttling engines, with the results now so well known. Some years ago he remembered receiving a specification for compressing air into a reservoir, with an arrangement for stopping or slowing the engine so long as the pressure was maintained, and starting it again when the pressure fell; consequently the engine would have the great advantage of working always against a constant load. Nevertheless great stress was laid on the variable-expansion gear with which the engine was to be fitted, and a cut-off was prescribed which was to vary from nothing up to 80 per cent. of the stroke. He remembered also reading a published professional description of some competitive economy trials, in which the engines ran for a certain number of hours against a constant load on the brake; and amongst the reasons for the triumph of the winning engine was enumerated the excellence of its variable-expansion gear. It was against such illusions that Mr. Willans entered the lists, in which he did such splendid work. In America the glamour of variable expansion had been and still continued a hindrance to progress.

(Mr. Mark Robinson.)

Long after compound engines had come into use in this country for nearly every purpose, simple engines were being contentedly used in America, in the firm belief that initial condensation and every other economic evil had been exorcised by variable expansion. To this day the American technical papers were full of lists of engines, whose whole claim to attention was the mistaken belief of their makers that the excellence of their variable-expansion governors in some way compensated for the extravagance of their steam consumption. In this country Mr. Willans had dispelled that illusion, and in regard to the smaller classes of engines had helped largely to place this country some years ahead of its competitors. To elucidate and apply fully the principles involved in the comparison of the two modes of governing, and to show what was and what was not to be gained by variable expansion, was what the present paper had done; and he thought it was an excellent and useful work. In fact he was inclined to doubt whether many engineers had known it all along; many he thought had known only an exaggerated and distorted tale, and would welcome a reliable exposition of the true state of the case.

Mr. Druitt Halpin mentioned that the drawings for the earliest of the American variable-expansion governors had been revised in England by Mr. Wilson Hartnell of Leeds, who had successfully endowed them with the close regulation which had brought them into such extensive use. He had himself also followed the subject pretty closely, as he had designed a variable-expansion shifting-eccentric governor some five-and-twenty years ago in conjunction with Mr. Arthur Rigg, by whom the arrangement had been matured. With respect to the claim made for expansion governors that they did such excellent work, some years ago he had tested two engines on the same day in what he believed was the only possible way of testing the efficiency of the governors, namely by means of a Moscrop recorder. One was a celebrated American engine with a close cut-off, and the other was a Willans engine; they were both electric-lighting engines with varying load; over the load he had no control, and had to take what came. The recorder being shifted from one engine to the other gave automatic records under nearly similar circumstances;

and the result showed that the variable-expansion governor on the American engine was not to be compared with the throttling governor on the Willans engine. Just as no description ought to be attempted of a valve-gear without an indicator diagram, so he considered no statement ought to be made concerning governors without an automatic record of their performance. At the compressed-air station in Paris (Proceedings 1889, page 552) he remembered seeing a gear at work in 1889 which was an instance of inverted action; for instead of the governor controlling the engine completely, the engine completely controlled the governor, and the latter really did nothing whatever towards governing the engine.

Mr. Alfred Saxon was glad it had not been attempted in the paper to lay down any hard and fast rule, because he considered in a question of this kind the conditions varied so much that it was almost impossible to do so. Like Mr. Longridge's (page 194), his own experience had been chiefly amongst slow-running engines for developing large power; and he was rather struck with the remark (page 165) that under a speed of 150 revolutions per minute throttle-valve governing need not be considered. In connection with the large engines that he had most to do with, it was the coal consumption that had as a rule been taken as the criterion of economy, which of course was an unfair sort of test in regard to the engine. But taking the coal consumption and not the steam consumption of the large mill engines with which he was acquainted, he had found that there were slide-valve engines working with throttle-valve governors which would compare favourably with any of the variable-expansion engines. In the throttling engines which were working so economically, the lap was arranged so that the valves should give the maximum steam for working at full load on Monday morning, or at the heaviest time possible, and the engines should then just run up to speed. The best engineers connected the throttle-valve with the governor by a right-and-left-hand screw, by means of which at the starting time, and for the first hour or so in the morning, the throttle-valve was regulated and adjusted by hand, so as to give it a greater opening than the position of the governor

(Mr. Alfred Saxon.)
in its mid position with the engine running up to speed would give it, whereby a greater volume of steam was allowed to pass through just for the time; and then during the day, under the ordinary conditions when the load did not vary much, the engines were kept working with rather less opening of the valve. With 100 lbs. boiler-pressure throttle-valve engines were working at 90 lbs. initial pressure in the high-pressure cylinder, and would compare favourably with many variable-expansion engines.

With regard to the engine referred to in the footnote on page 156, which had been running at 400, 300, and 200 revolutions per minute, he should be glad to know whether it had been originally designed to run at the highest speed of 400 revolutions per minute: because if it was not so designed, but was designed to run at only 200 revolutions, with ports and pipes suitable for this lower speed, there would manifestly be a great deal of wire-drawing and a good deal of loss in the steam supply when running at double speed. Because any engine was running quicker than the speed for which it had been designed, it ought not to be taken for granted that the advantage gained by diminished condensation of steam would not be counter-balanced by the deficiency in steam supply. He should therefore like to know at what speed the engine had really been designed to work permanently.

In engines fitted with variable-expansion gear, he thought the difficulty of increased condensation when the cut-off was early might be met by setting the stop-valve so that the steam should be considerably wire-drawn. If the stop-valve were so regulated, the cut-off might take place at the most suitable point in the stroke without entailing the awkward consequence of large initial condensation. This had been done in one or two engines that he knew of, and it gave an advantage over the use of a variable cut-off alone for a varying load. It was indeed a reasonable compromise between throttling and variable expansion, such as he gathered was adopted in the working of locomotives, which among high-speed engines he believed had by far the widest field.

In constructing a throttle-governed engine for working at a load which was not known beforehand with absolute certainty and might

vary a little from the calculated load, he should be glad to know whether the author would prefer to make the slide-valve with too much lap, and afterwards have any excess machined off so as just to suit the requirements of the actual load; or whether he recommended calculating merely the amount of lap to suit the supposed load, and then adding lap-pieces if the actual load should turn out to be less than had been anticipated. In his own opinion lap-pieces were really dangerous, and it was desirable they should be avoided if possible. In compound engines this was a matter which concerned not the high-pressure cylinder alone, but equally the other cylinders also, as had already been pointed out (pages 184–5) in regard to the variable-expansion gear as a whole.

The power of the fly-wheel seemed to him to be the vital point in good governing; and its efficiency in controlling the speed ought to be even greater, he considered, in steam engines than in gas engines. Many gas engines had only one impulse in every two revolutions, whereas a single-cylinder steam engine ordinarily took steam twice in every revolution, or four times if there were two cylinders working cranks at right angles. If therefore fly-wheels applied to steam engines were similarly proportioned to those used on gas engines, they ought certainly to produce better governing in high-speed steam engines than in gas engines.

The paper he thought was a model in respect of cautious investigation upon the basis of the author's large experience with high-speed engines, with which it was evident that he was thoroughly conversant. It was an eminently good explanation of the whole subject of throttle and expansion governing; and the care with which it had been prepared was evidenced in the pains taken to guard against the statements it contained being understood to mean more than was intended by the author.

Mr. G. M. Clark noticed that in Plates 25 and 26 the load-curve was given from the Kensington Court electric-lighting station, and from that curve the water had been calculated which ought to be consumed by the engines running in the station. The calculations however were founded not on the actual Kensington Court engines,

(Mr. G. M. Clark.)
but on similar engines which had been tested at the works of Messrs. Willans and Robinson at Thames Ditton. The results were given in page 171, and were respectively 110,330 and 102,100 lbs. per twenty-four hours for the two methods of governing by throttling and by variable expansion. After the engines had been tested at Thames Ditton, and before they were got to work in the electric-lighting station, they had to be taken down, removed from the works and re-erected at the station; and it might not appear extraordinary therefore if any slight difference in the setting of the valves were to produce a considerable influence on the water-consumption of the engines. Moreover the fact was well known that in no electric-lighting station was such a low water-consumption ever obtained as that given in the paper. During the last few months he had been engaged, under the direction of the President, in carrying out several tests in connection with three electric-lighting stations in London; all three were working with low tension, and the whole power was supplied by Willans engines. A principal point in the tests was to account on the steam side for the whole of the water fed into the boilers; and as the whole of the work was done by Willans engines, the consideration arose whether the tests previously made at the works at Thames Ditton should be accepted, or whether fresh tests should be made at varying loads. As there were nearly thirty engines in the three stations, and it would have involved at least a hundred trials to test them all satisfactorily, he had decided to try one station as a whole under the conditions of a light summer load and a heavy winter load, in order to see whether the previous tests at the makers' works gave the means of accounting for the whole of the water actually consumed. The results were shown in Figs. 38 and 39, Plate 33, in which the central vertical scale of percentage was common to both; each diagram had also its own separate scale of actual water-consumption per kilowatt-hour. The water measured into the boilers was taken over any convenient period, either for eight hours a day or for a week; and the total of the kilowatt-hours produced by the station was measured for the same period. Dividing the water by the kilowatt-hours, the

average consumption per kilowatt-hour was found to be 48 lbs., Fig. 38, with the light summer load when the work of the station was about 9,000 kilowatt-hours during a week. According to the makers' previous trials of the engines, the water which ought to be used for the same work, when the engines were running at full load only, would amount to $32\frac{1}{2}$ lbs. per kilowatt-hour, which represented 67 per cent. of the total water used in the station, as shown at the bottom of Fig. 38. Since however the engines were not running at full load, but had a lower load, the water calculated from the makers' tests for the actual load came to about 42 lbs., which amounted to 88 per cent. of the total water used in the station. An auxiliary engine was also employed to work the feed-pump for the boilers; and the steam so consumed, being condensed separately and weighed, was found to amount to from $2\frac{1}{2}$ to 3 per cent. of the feed-water pumped: that is to say, each pound of steam pumped from 30 to 40 lbs. of water. Adding this 3 per cent., as shown in Fig. 38, the previous 88 per cent. was raised to 91 per cent. The water from the drains and separators was all collected in a sump, from which it could be pumped out and weighed; and this, as shown at the top of Fig. 38, amounted to about the remaining 9 per cent. of the whole water to be accounted for. Similarly Fig. 39 represented the apportionment of the water-consumption for the much heavier winter load of 3,350 kilowatt-hours during twenty-four hours. The several percentages were nearly the same, the only saving being in the load factor of the engines; and the water-consumption per kilowatt-hour worked out at 46 lbs., instead of the 48 lbs. in Fig. 38. From these diagrams it would be seen that, even though the water collected in the drains and the steam used for the feed-pump might not be measured with extreme accuracy, still the whole of the water that was being used in the station was here accounted for, of which by far the larger proportion was that used in the engines. It might therefore be concluded that the previous tests of the engines at the makers' works at Thames Ditton could be relied upon, and that the Willans engines might be regarded as probably the best calibrated instruments in the station.

Capt. J. H. L'E. Johnstone, referring to the experiments plotted in the diagram, Fig. 25, Plate 29, asked whether the curves representing water consumption with throttle governing and water consumption with varying boiler-pressure showed any tendency to diverge when the mean pressure became lower; if they did, it would tell in favour of throttle governing. The difference between the two lines where they were widest apart had been stated by the author to represent only about $1\frac{1}{2}$ per cent. economy in favour of throttle governing; but this could hold only for the mean pressures at which the particular experiments plotted in the diagram had been made, for the two lines in Fig. 25 appeared to meet where the throttle-valve would be full open, and to diverge as it became closed. As the total consumption was becoming reduced while the lines diverged, it seemed to him that the above percentage must evidently increase considerably at the lower mean-pressures.

In searching for the conditions under which it might not be an advantage to govern by variable expansion, he found that in almost every section of the paper, after a good deal of discussion, the conclusion seemed to be arrived at that it was best to govern by variable-expansion gear. Those were indeed the concluding words of the paper; but certain cases had been indicated in which the advantage might be but slight, if any at all; and he thought a good many engines with which he had lately had to deal were fair examples of this kind. They were small non-condensing engines for electric lighting, and were working with fairly high boiler-pressure and at fairly high speed; and practically they were working always either at their full load or at a very light load, because as a rule the full number of lights was required at once, or else only a very small number. Looking at Fig. 8, Plate 23, he thought it would be seen that under such conditions the economy of a non-condensing engine governed by variable expansion would be but little greater than that of a throttle-governed engine; and he should like to know whether this tallied with the author's experience.

Mr. W. Worby Beaumont thought the gist of the paper would be found in the first few paragraphs, which to himself certainly

eemed to meet the wish expressed by Mr. Donkin (page 199) for a ummary of the paper. It had long been well enough known that under many circumstances engines might work, and did work, as conomically with the throttle-valve as with the most elaborate cut-ff gear; and, as remarked by Mr. Robinson (page 203), it had been musing to read grave statements of engines running under a dead oad and doing so well because they had variable-expansion gear, when in fact the gear must have been perfectly inactive throughout he whole time of running. The instance adduced by Mr. Longridge page 195) was one in which the advantages of variable-expansion gear night and did in practice come into play and bring about considerable conomy, although for the greater part of the period during which nill engines were working it might be more or less inactive: that is o say, variable expansion would be advantageous during the first ew minutes or the first half-hour after starting a mill engine, and gain for a short time before stopping. But valuable as the xpansion gear was, he thought there were no doubt many engineers who assumed that, because it was good in some instances, it must be good in all. The great value of the paper really consisted in the areful way in which it not only pointed out that the throttle-valve night be in many instances a better means of governing, because ufficient and at the same time so simple, but also pointed out where t was that throttling was not so good, and where the other method hould be used. In his opinion the author ought to be congratulated on having had the courage to come forwards and say what he had said n favour of the simpler form of governing, for it was certain that not every engineer would have liked, in view of the great estimation n which the cut-off gear was held, to say as much as he had said concerning the throttle-valve, although it was perfectly true.

There was a further reason, which had not yet been touched upon, for agreeing with the paper in regard to the value of throttle-valve governing, although for most cases it might be shown theoretically that the variable cut-off was the better. At the commencement of the paper it was stated that governing by throttling might be described as constant expansion with variable pressure; while the system commonly called automatic was constant pressure with variable

(Mr. W. Worby Beaumont.)

expansion. Throttle governing therefore appeared to involve the question of possible gain from the difference between the heat expenditure on the one hand in generating the steam at a higher pressure and then using it at a lower pressure after throttling, obtaining whatever advantage might be derived from the slight superheating and drying of the steam by wire-drawing; and on the other hand in the generation of the larger volume of steam at the lower pressure to which it was actually reduced by the throttle-valve. In throttling from a higher boiler-pressure it seemed to him that steam was being used which had not been taxed with the full proportion of the latent heat or of the external work of evaporation; whereas with a lower boiler-pressure, which did not require throttling, the steam used had been taxed with the full amount of latent heat. In brief it might be said that, to the extent to which the constant expansion involved variable pressure, there would be evaporation under constant volume. If this view were not correct, perhaps the author would show where it was inconsistent with his definitions of the two systems of governing. At all events it might serve to suggest that, behind the reasons which had been advanced in connection with locomotive practice and with the starting and stopping of mill engines, there might be yet other reasons to account for the good results obtained with the throttle-valve.

Professor Archibald Barr thought the paper would do good service in calling the attention of engineers in general to what no doubt many had had under consideration before. It seemed to him that it would form the starting point for a number of most interesting and valuable experiments; for although a subject of this kind was properly brought forwards for the first time in the way in which it had been dealt with in the paper, it would be of even greater value when the results of experiments on other kinds of engines were brought to bear upon it; and no doubt many such experiments would now be made and recorded, which would be of great value for future guidance. It should be remembered that the right way to make such experiments was not to try an engine governed by the throttle-valve against another engine governed by variable expansion;

but to take one engine at a time, and to drive it neither with variable expansion nor with throttling, but with a constant load on the brake for each experiment, varying the load successively and varying the expansion by hand to correspond, without using a governor at all; and then to make a second series of experiments with the same engine, with a throttle-valve adjusted by hand for the same succession of loads on the brake. Experiments made in this way he thought would give a fruitful subject for investigation in engineering laboratories; and he would recommend those of his colleagues who were in a position to make such experiments to do so, and to record them in the Institution Proceedings. When more experiments had been made, and had been plotted in the same manner as those shown in the paper, he had no doubt the question would be fully cleared up; and in the matter of economy he thought there would probably be found to be even less advantage from expansion governing than at present appeared. With regard to the generation of the steam (page 212), he thought there was not any difference between throttling and variable expansion, because he understood from the paper that it was always assumed that the steam, having been generated at a given pressure, was either admitted into the cylinder at that pressure in the one case, or was throttled from the same pressure in the other case. The boiler did not know what was going to be done with the steam, and in both cases was generating the steam at constant pressure. The comparisons drawn in the paper therefore he thought were correct in this respect.

Capt. Sankey pointed out that Mr. Longridge's remarks (page 195) confirmed the conclusion arrived at in the last example given in pages 177–8. The additional power required for starting on Monday morning had not been mentioned, it was true; but he had considered the contingency of the boiler-pressure falling through any cause by as much as 20 lbs., and also the possibility that the load might be higher than had originally been anticipated. The figures given were of course not absolute, but were simply the working out of an arithmetical example to illustrate

(Capt. Sankey.)
the principle; they showed a gain of about 6 per cent. by the use of cut-off gear instead of throttling. In this connection he should like again to call attention to the remarks in page 155 of the paper, where it had been pointed out that all the various figures and curves had been determined from Mr. Willans' experiments: with the exception of Fig. 8, Plate 23, which was based upon the average results of all ordinary commercial trials made at the works at Thames Ditton. Several speakers had hesitated to accept the results as applicable to all engines; but although it was evident that the absolute results would vary with the kind of engine employed, still the general conclusions arrived at he felt sure would be maintained. In fact all the conclusions in the paper, with the exception of the advantage of throttling at very light loads, could have been deduced from a consideration of the theoretical consumption-curves given in Fig. 1, Plate 20; but he was sure engineers would rather see arguments based on the consumption-lines of an actual engine, even though it represented a special type.

To give any sort of summary, as asked by Mr. Donkin (page 199), beyond what had been said in page 169, was in his opinion not possible; as pointed out by Mr. Saxon (page 205), no hard and fast rule was practicable. It was for this reason that he had worked out several numerical examples, desiring thereby to show that every case had to be tried on its own merits, and also to exemplify the way in which the different cases might be examined and decided upon individually.

With regard to the experience of locomotive working, referred to by Mr. Joy (page 201) and Mr. Johnson (page 202), their results he thought could be explained by Fig. 8, Plate 23. Although this diagram referred to a compound engine, yet the point material to the argument was the crossing of the two consumption-lines; and this crossing of course occurred also with a simple engine, though probably not at 25 lbs. mean pressure, but possibly higher. Taking the consumption-lines for the non-condensing engine as applying to the locomotive, it would be observed that, from a load corresponding with about 54 lbs. mean pressure per square inch down to about 25 lbs. mean pressure, the variable-expansion

governor or link motion would have the best of it, but that below 25 lbs. the throttle-valve governor, that is in the locomotive the regulator, was most economical; it therefore depended on the amount of load as to which mode of regulation should be used. It might not be unreasonable to suppose that in the trials mentioned by Mr. Joy the average load was in the neighbourhood of 25 lbs. mean pressure, in which case there could be no difference between the two methods of regulation. It ought however to be borne in mind that a locomotive engine was a law unto itself. There was the peculiarity that the compression line in the indicator diagram was necessarily varied by altering the cut-off; and on this account it was much more difficult to make a theoretical comparison of economy between the two modes of working, by the regulator or by the link motion. With the opinion expressed by Mr. Joy (page 201), that the best results, especially in engines for electric traction, would be obtained by a judicious combination of the two plans, he fully agreed; and would point out that he had already drawn attention in page 163 of the paper to the advantage of being able to combine the two methods; and it was on this twofold plan that the Willans engine, when fitted with variable cut-off gear, was governed.

He was glad to have Mr. Halpin's confirmation (page 205) of what had been stated in the paper with regard to the sensitiveness of the two kinds of governors.

Mr. Saxon's experience with mill engines—namely that there was no noticeable difference economically between similar engines governed by either method—was precisely what he should have expected, judging from the result of the mill-engine example (page 177). It was true that in the particular instance chosen a saving of 6 per cent. was shown in favour of the variable cut-off gear; but in the example allowance had to be made for uncertainty in the maximum load, an uncertainty which Mr. Saxon dealt with in another way. If this allowance were not made, the gain would drop to 4·9 per cent.; and it was evident that, in comparing the coal economy of a number of mill engines, other sources of loss and gain would quite overshadow so small a difference as 4·9 per cent.

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The particular engine referred to in page 156, about which Mr. Saxon had enquired (page 206), was designed to run at 500 revolutions a minute, with a slight throttling of the steam with full load at that speed. Therefore at 400 revolutions, and still more at lower speeds, there would be practically no throttling. The reduction observed in economy as the speed was lowered was really due to the fact that there was more time for initial condensation to take place at the lower speed. It had been noticed by Mr. Saxon that it was advantageous to wire-draw the steam by means of the stop-valve, when working at light loads; and this was a strong confirmation of the statement made in page 163 of the paper respecting the advantage of throttling at light loads. Using the stop-valve for the purpose was of course quite permissible when the load varied but slowly, as was the case with many mill engines; but with a rapidly varying load the advantage could be gained only by having a throttle governor, or a cut-off which restricted the port opening at light loads. As regarded Mr. Saxon's practical remarks about lap-pieces for slide-valves (page 207), his own experience had not been with the same class of engines, and he regretted therefore he was unable to give any information on that point.

He had been much struck by Mr. Porter's remarks as reported by Mr. Donkin (page 200), because they appeared to him to herald sounder views in the United States on the subject of governing: by which he meant that too much weight was there given to excellence in governing, relatively to other qualities of an engine. In his own opinion the advantage of throttle governing had been exaggerated by Mr. Porter; but under the circumstances that was probably inevitable. The increase of initial condensation as the cut-off became earlier and earlier, referred to by Mr. Porter, had been mentioned in page 159 of the paper; and it was one of the reasons why expansion governing did not give the economy which might be theoretically expected from it, and why at light loads it was actually less economical than a fixed cut-off.

The governor curves exhibited by Mr. Allen in Figs. 33 to 37 Plate 32, were most interesting, more particularly as they showed that the effect of the floating wheel attached to his governor (page 199)

was to reverse the usual effect of the fly-wheel when sudden changes of load occurred. This point he hoped would be thoroughly investigated by Mr. Allen, as it was of great importance and interest.

The water-consumption deduced from the load curve in Plates 25 and 26, which had been referred to by Mr. Clark (page 208) as lower than had been reached in any electric-lighting station, was so for two reasons. The first was that the cylinders of the engines on which the calculations were based were differently proportioned from those of the Willans engines at present in general use. The second reason was that the calculated consumption was not the total consumption of the station, but represented only the steam actually used in the engines, taking account of the load-factor. The steam required for the feed-pumps &c., and that collected as water from the drains and separators, and that lost by leakage, had however to be accounted for. These latter additions had been dealt with by Mr. Clark, and the results presented in his diagrams, Figs. 38 and 39, Plate 33. He much appreciated Mr. Clark's concluding remarks, corroborating as they did the results of the calculations made in the paper.

In Fig. 25, Plate 29, about which Capt. Johnstone had asked a question (page 210), the experimental points showed no indication of curvature; if such curvature existed, it was within the limits of experimental error. The case referred to by Capt. Johnstone, of an engine working either at full load or at a very light load, was clearly one in which a throttle governor ought to be used. At full load there would evidently be no difference in economy between the two modes of governing; and at very light loads the economical advantage would be in favour of the throttled engine.

The question referred to by Mr. Beaumont (page 212), respecting the advantage that might be derived from the slight superheating and drying of the steam by wire-drawing, was the same which had been raised by Mr. Peache (pages 183–4) and Mr. Paul (pages 188–9), and to which he had already replied. Mr. Beaumont however went further, and appeared to think that in a throttling engine the full latent heat was not required for evaporating the feed-water, and that herein were reasons to account for the good results obtained with

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the throttle-valve. He himself did not think so, because the total heat of evaporation, that is at constant pressure, had to be put into the steam in the boiler, and the excess superheated the steam and produced eddies. Returning to the question of the slight advantage gained by wire-drawing, it would be observed that the comparison had been made on the basis of water per indicated horse-power. The true basis of comparison however was the percentage of heat-units utilized, or in other words the "thermal efficiency." The whole matter could be exhibited on the theta-phi chart, as shown in Fig. 40, Plate 34. In the example here chosen it was supposed that the steam was produced at a pressure of 160 lbs. absolute, and then reduced by throttling to 80 lbs.; the steam would thus be superheated, and would reach the state defined on the chart by the point P, the area C + D being equal to the difference in the total heat of evaporation at 160 lbs. and at 80 lbs. respectively, namely 1192·7 less 1177·0, equal to 15·7 B.Th.U. If the feed-water came into the boiler at 150° Fahr., which was also supposed to be the release temperature, the heat required to evaporate at 80 lbs. absolute was represented by A + B. The heat utilized per lb. of feed-water in the non-throttled engine was equal to A, or 204·6 B.Th.U. in this example; but in the throttled engine the heat utilized per lb. of feed-water was A + C, or 208·2 B.Th.U., showing an improvement in respect of feed-water of a little under 2 per cent., as already stated in page 192. But the thermal efficiency of the non-throttled engine was $A \div (A + B) = 204 \cdot 6 \div 1058 \cdot 6 = 0 \cdot 1933$; and the thermal efficiency of the throttled engine was $(A + C) \div (A + B + C + D) = 208 \cdot 2 \div 1074 \cdot 3 = 0 \cdot 1936$, or only 0·18 per cent. better. It was clear from the geometry of the figure that $(A + C) \div (A + B + C + D)$ was greater than $A \div (A + B)$; but the numerical example showed how very little greater. He had also worked out other numerical examples with the same result.

He wished fully to endorse Professor Barr's remarks (pages 212–3) as to the correct method of experimenting, when testing the comparative steam-consumption according as the pressure or the cut-off was varied; and it was just the method Mr. Willans had adopted, with the exception that, when varying the power with a

fixed cut-off, the boiler pressure had been reduced in the boiler itself, instead of throttling the steam by a stop-valve.

In writing the paper he had endeavoured to be quite impartial, not favouring either method of governing; and judging from the remarks made in the discussion, he believed he had succeeded in this endeavour, because it seemed to him that one half of the meeting thought he was in favour of throttle-valve governors, and the other half in favour of variable expansion.

The President was sure the Members would join in passing a cordial vote of thanks to Capt. Sankey for his paper, to which he had himself listened with special interest. There was no doubt that the author's treatment of his subject was both valuable and original. It was so easy to come to dogmatic conclusions on a subject like this without any experiments whatever, that naturally the literature of the steam engine was full of positive statements on the matter. Unfortunately few engineers possessed anything like the necessary data for working out the subject thoroughly. Happily the author not only possessed these data to an extent to which they probably existed nowhere so fully as in his own works, but also possessed in a high degree both the critical faculty necessary for dealing with the facts, and the literary faculty for presenting them in a fashion which could be understood. Moreover the system of diagrams which the author had used was singularly clear, and would enable other engineers to apply his results to their own work without much difficulty, by the exercise of reasonable judgment. As the paper referred so much to cases like electric-light stations, where the total plant was divided into many small units, it became necessary to remember that, although only 70 per cent. or 50 per cent. or even a lower percentage of the total plant was being used at once, yet still all the units actually in use, excepting only one, might or would be running nearly at full power. Thus in a station where there were ten units, it might well be sufficient to arrange that eight of these should be so schemed as to be most economical at full load; while two only need be so arranged as to work with special economy at low loads, these two being reserved in the station for taking up

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fractional loads. In this way the advantages of maximum economy might be gained, while any disadvantages inherent in a somewhat complicated apparatus might be avoided. These considerations of course did not affect such a case as the driving of a factory, where the whole power was concentrated into a single unit. He was exceedingly glad that the Institution of Mechanical Engineers was able to have in its Proceedings a paper of so much originality and so much practical value as this by Capt. Sankey.

Mr. JOHN G. HUDSON wrote that the author's examination confirms the opinion generally held as to the advantages of expansion governing; and he appears to hold that throttle governing need be considered only for speeds beyond the working limit of Corliss and other trip-gears. In the paper this limit is placed at about 150 revolutions per minute (page 164), which is perhaps permissible for very small engines; in the United States indeed speeds of 160 to 170 revolutions per minute are said to have been obtained with specially designed Corliss gear. For larger engines however, where the inertia of the parts of the gear becomes considerable, the writer regards from 80 to 130 revolutions as about the highest speeds consistent with safety and durability. For speeds beyond the range of trip-gears, some positive or non-detaching gear must be employed; and it is to be regretted that the scope of the paper did not permit the author to deal with the mechanical and financial aspects of the question, inasmuch as the choice between throttle and expansion governing really turns rather on the question whether a sufficiently simple, inexpensive, and efficient expansion-governor can be applied to such engines, than on the abstract merits of the two systems. At the present time the choice is practically limited to valve gears of two kinds: those controlled by shaft governors acting either on the main or on the cut-off valve; and those controlled by ordinary independent governors acting either on the main or on the cut-off valve through some form of link-motion. The difference between them is more apparent than real, the action in each case being

virtually equivalent either to that of a reversing link-motion, or to that of a single eccentric of varying angular advance. The objectionable features of these gears are the too constricted port-openings at early points of cut-off, and the enormous governor-power generally needed to control them efficiently. Relay governors have been applied to overcome the latter difficulty, but they have usually been found liable to hunt badly, though this imperfection ought not to be an insuperable one; and piston-valves and other balanced valves have been employed to reduce the power required from the governor. It is presumably in view of these imperfections that the author raises the question whether it might not be better to adopt the much simpler throttle-governing, in cases where the conditions allow this to be done with only a moderate reduction in steam economy; and the suggestion is well worth consideration. An element in the problem is whether throttle-governing can give sufficiently steady running under varying conditions: a result which is certainly not usually obtained from the throttle-governors commonly met with, but perhaps this might be overcome by careful designing. Incidentally the author touches on the convenient way in which trip-gearing lends itself to controlling the cut-off in more than one cylinder in compound or triple-expansion engines; and the writer having employed the method in two-cylinder compound engines can confirm the statement as to the improvement which can thus be effected in the governing, where the conditions are difficult.

As regards the arrangement suggested by the author (page 163) of combining throttle and expansion governing, the writer is informed that this was frequently employed in mill engines before the general adoption of trip valve-motions; and examples are still, or were recently, to be found in some of the older engines in the Lancashire district. The object however was not quite that contemplated in the paper, inasmuch as the throttle-valve was provided as a safety appliance to deal with any large variations of load, during the time needed by the variable-expansion gear to adjust the cut-off to the load, the expansion gear being of some slow-action kind, actuated by ratchets, friction cones, or toothed gearing.

Mr. William Sisson wrote that the paper is of great interest and value to those who, like himself, are engaged to a considerable extent in the construction of electric-light engines and other engines with very variable loads. There is no doubt that, as pointed out in page 155, the comparison of indicator diagrams alone is not sufficient for enabling a correct judgment to be formed as to the best mode of governing. In almost every case of engine regulation with a more or less variable load he has been accustomed to recommend and fit variable-expansion gear; and he is glad to find that with few exceptions the conclusions arrived at in the paper support this view. There are two points however, which do not appear to be adverted to and are of considerable importance, namely compression and clearance; and it would be interesting to know whether the engines whose performance is exemplified in Figs. 3 and 4, Plate 21, were fitted with expansion gear which increased the compression at earlier cut-off, and whether the clearance was large in proportion. If the compression did not increase, and if the clearance was considerable, it would go far to explain the relatively smaller advantage of expansion governing at the higher initial pressure (page 158), because with the higher pressure and consequent earlier cut-off the clearance volume of steam would be greater relatively to the total volume used. To the use of increasing compression the writer is inclined to attach great importance, believing that it goes far to compensate for the drawbacks to the use of higher pressure, referred to in page 159, and is especially important in either a simple or a compound non-condensing engine working under variable loads and governed by variable expansion. In both engines, not only is there attained the filling of the clearance spaces and the partial drying of the compressed steam, but also, owing to the loss of area in the compression corner of the indicator diagram, the whole steam-line is raised, and the pressure is not allowed to fall so low towards the end of the stroke, thus avoiding the formation of a negative area even with a considerable variation in the load.

Another point to be noticed in comparing Figs. 3 and 4, Plate 21, is that, with a light load, high initial pressure, and throttle governing, the pressure in the steam-chest is not likely to be uniform; but the

initial pressure on the piston is probably higher, and falls during the admission as the velocity of the piston increases, thus giving the throttling engine effectively some of the advantage of greater expansion, while the variable-expansion engine is affected by greatly restricted port-openings. The latter circumstance causes the action to approach to that of throttling, and still further tends to explain the small relative benefit of variable-expansion governing at the higher steam-pressure, while compression and clearance tend to explain the considerable discrepancy between the theoretical and actual lines in these diagrams, Figs. 3 and 4. The extent of compression must of course be limited by the consideration that the internal friction of the engine is increased thereby, and the mechanical efficiency or ratio of brake horse-power to indicated horse-power is consequently reduced.

Though less extensive than the author's, the writer's experience is entirely in favour of applying variable-expansion gear to each cylinder of a double or triple compound engine, on the grounds both of prompter and closer regulation and also of economy in steam; and his firm have not made any such engines without this arrangement. Its effect on the regulation of speed is illustrated by two recent double-crank compound engines, working at 150 and 250 revolutions per minute, in which the variation of speed from no load up to full load of about 50 brake horse-power is only about 2 per cent. In regard to accuracy of regulation with variable-expansion shaft-governors, from his own experience there appears to be little difficulty in securing this desideratum within about 2 to 2½ per cent. from running empty up to full load, even in small engines. The whole secret is to make the governor as powerful as the diameter of the fly-wheel will admit, to reduce its internal friction to a minimum, and to use piston-valves except in small engines; as pointed out in the paper (page 167), a relatively heavy fly-wheel is of course essential. There is no practical objection to increasing the governor power as above recommended; for the governor weights form part of the weight of the fly-wheel, and the cost is but little increased by increasing the power. For the continued efficiency of these variable-expansion shaft-governors

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actuating directly a main slide-valve or valves, means of constant lubrication should be carefully arranged; for, as far as the writer has been able to judge, the closeness with which the speed can be regulated, subject to the condition of freedom from hunting when running with no load, is almost entirely dependent upon the internal friction of the governor.

As rolling-mill engines have been alluded to in the paper (page 178), it may be of some interest to exhibit indicator diagrams taken from a double-cylinder rolling-mill engine controlled by a throttle-valve governor, for which the writer is making two powerful variable-expansion shaft-governors. The diagram, Fig. 43, Plate 35, taken when the engine was running entirely empty, shows a mean effective pressure of only about 4 lbs. per square inch, and about 120 I.H.P.; while in Fig. 44 the outer line, taken in the first pass through the roughing rolls, gives a mean effective pressure of rather more than 53 lbs., and nearly 1,500 I.H.P. In Fig. 45 the outside line is nearly the same; but the innermost line shows a wasteful distribution, as the throttling governor has caused the pressure to rise during the stroke up to the point of cut-off, so that the weight of steam in the cylinder at that point has not done its proper work. In both the first and second passes through the roughing rolls the maximum power shown by any of the indicator diagrams taken does not vary greatly between 1,200 and 1,500 H.P.; but in the third pass through the roughing rolls the power falls considerably, and still more so in the fourth pass through these rolls as well as in the several passes through the finishing rolls: so that there appears to be good scope for a considerable economy through the application of variable-expansion gear. For so low a power as is exemplified in Fig. 43, it is of course not supposed that such gear will be any improvement whatever; and in fact there will be a waste of power, because the initial pressure on the piston, and consequently the friction, will be considerably increased beyond what is shown in Fig. 43. But during the process of rolling there is a sufficient range of power to give good scope for variable expansion, while yet the power does not fall so low as to render the result un-economical. The valves are piston-valves, and it is wished the

engine should be able to develop 1,800 I.H.P. as a maximum in case of need.

Mr. Philip Dawson wrote in regard to electric traction, which is dealt with in pages 173–6 of the paper, that he believes it will undergo a great extension during the next few years. Ten years' experience in America has led there to the nearly universal adoption of direct-coupled engines and dynamos in the power stations, the engines being mostly horizontal Corliss. For small stations up to 1,000 H.P. either slow or high-speed engines are used, driving the dynamos through belts; but he does not see why for any size direct coupling should not be resorted to, if the engines can stand it. To the data furnished in the paper respecting the special conditions to be fulfilled by steam engines working electric tramways, it may be of interest to add that the average load on such engines not only varies between fairly large limits, as in electric lighting, but is made up of a large number of extremely heavy and light loads succeeding one another with great rapidity. Thus in a series of ammeter readings taken every fifteen seconds during one hour on the fairly level road of the City and Suburban Railway, Baltimore, with sixty motor-cars running, the ammeter fell nine times to 400 ampères, rose nine times to 1,400, and twice to 1,600, the average load being 900 ampères. Once the current rose from 400 up to 1,600 ampères within ten seconds, and forty times there were changes of 600 ampères within ten seconds: or, in other words, changes of 420 electric H.P., when the average output was only 630 E.H.P. and the maximum reached 1,120 E.H.P. This shows the importance of rapid and economical governing in electric traction. Generators and motors have been so designed that from one-third up to their maximum capacity they have an efficiency but little below their maximum efficiency; and with engines doing the same it may be hoped in time to obtain a total efficiency of 60 per cent. for an electric road. The adoption of electric traction upon tramways, and upon urban and light railways, will open a vast new field to steam-engine builders. In Europe there are at present in operation 460 miles of electric roads, working 1,260 cars, and equipped with

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engines of about 25,000 H.P.; before the end of this year there will be in service 390 miles more, with 960 more cars, and engines of about 18,000 H.P. more. In America there are at present roundly 9,000 miles of track, working 20,000 cars, with engines of over 800,000 H.P.; and there are several individual stations of from 15,000 to 30,000 H.P. each.

Mr. FRANK GARRETT wrote that, having recently completed at Leiston Works a series of trials with the view of ascertaining the advantages and disadvantages of variable expansion by means of a crank-shaft governor in portable steam engines, both single-cylinder and also double-cylinder compound non-condensing, he had the pleasure of submitting the results, which would be found to support in a remarkable degree some of the conclusions arrived at in the paper.

The engines tested at Leiston Works were, firstly a pair of single-cylinder engines of 9 inches diameter and 12 inches stroke, Nos. 19,530 and 19,747, of which the results are given in Table 2 (page 228); and secondly a pair of double-cylinder compound non-condensing engines of $7\frac{3}{4}$ and $11\frac{1}{2}$ inches diameter and 12 inches stroke, Nos. 19,634 and 19,751, of which the results are given in Table 3 (page 229). The two engines of each pair were exactly alike, differing only in the method of governing: one engine in each pair was fitted with a throttle-valve governor, and the other with an expansion-governor acting directly upon a single slide-valve. The trials were not made with a view to publication; and as the four engines tested were all new and of the ordinary commercial kind and construction, the several percentages of mechanical efficiency are lower than would be the case after they had run down to their bearings.

Taking first the single-cylinder engines, Table 2, the trials were made at three different loads of approximately 20, 15, and 10 brake horse-power; and it is especially noticeable that the economical results, given in terms of water consumed per indicated H.P. per hour, vary exactly in accordance with the author's experience. With the engine governed by the throttle-valve, the consumption slightly

decreased with the increase in load: whereas with the engine controlled by the expansion-governor, the water per indicated H.P., which was 28·51 lbs. with 14·58 H.P., diminished to 27·83 lbs. with the most economical load of 18·73 H.P.; after which it again increased to 28·41 lbs. with 24·40 H.P. The advantage as regards economy is always in favour of variable expansion: the greatest gain, as measured by the consumption of water per indicated H.P., is 12·3 per cent. with the most economical load; and the least gain is 9·9 per cent. with the heaviest load. It is interesting to observe however that the real economy with variable expansion must be sought in the results as measured by the consumption of water per brake H.P.; because with smaller loads the mechanical efficiency decreases rather rapidly, varying in these trials from 80·4 per cent. with the most economical load of 15·06 brake H.P. to 68 per cent. with the smallest load of 9·94 brake H.P.; and the economy of the variable-expansion engine as compared with the throttle-valve engine also diminishes from 15 per cent. with the most economical load to 9 per cent. with the lightest and 10·8 per cent. with the heaviest load. These results are also in accord with those given in the paper.

Passing now to the trials in Table 3 with the double-cylinder compound non-condensing engines, from which results are given with four loads of about 40, 30, 21, and 12 brake horse-power, the gain in economy by the employment of variable expansion is not so marked as with the single-cylinder engines; it is greatest, namely 6·7 per cent. per indicated H.P. and 16·4 per cent. per brake H.P., with the smallest load of 12·47 brake H.P.; whereas with the heaviest load of 40 brake H.P. it diminishes to 4·4 per cent. and 2·8 per cent. per indicated and per brake horse-power respectively. As the load diminishes, the mechanical efficiency of the compound engines consistently diminishes, from 79·3 per cent. to 72·6 and 69·0 and 55·3 per cent. with the throttle-valve governor, and from 77·9 per cent. to 76·1 and 72·0 and 61·7 per cent. with variable expansion, for the four loads respectively.

The results of these trials prove conclusively that in these small engines the gain in economy of water per indicated H.P. by variable

continued on page 232.

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TABLE 2.—*Comparative Economy of Governing by Throttling and by Variable Expansion in Single-cylinder Portable Engines.*

Cylinder 9 inches diameter and 12 inches stroke. Boiler Pressure 85 lbs. per square inch above atmosphere.

No. of Engine		19,530	19,747	19,530	19,747	19,530	19,747
Governing by Throttle-Valve or by Variable Cut-off		Throttle.	Cut-off.	Throttle.	Cut-off.	Throttle.	Cut-off.
Initial pressure in cylinder, above atmosphere	lbs. per sq. inch	75	83	69	82	57	82
Mean effective pressure from indicator diagrams	lbs. per sq. inch	43·0	42·9	31·7	33·0	25·4	25·5
Cut-off, percentage of stroke	per cent.	50	37	50	31	50	17
Revolutions per minute	revs.	147·2	118·1	150·0	148·6	152·9	119·1
Indicated horse-power	I.H.P.	24·50	24·40	19·50	18·73	14·83	14·58
Brake horse-power	B.H.P.	20·05	20·10	15·20	15·06	10·16	9·91
Mechanical efficiency, 100 × B.H.P. ÷ I.H.P.	per cent.	82	82	78	80·4	69	68
Steam consumed per indicated H.P. per hour	lbs.	31·53	28·41	31·75	27·83	32·21	28·51
Saving of steam	per cent.		9·9		12·3		11·5
Steam consumed per brake H.P. per hour	lbs.	38·53	34·40	40·73	34·62	41·07	40·10
Saving of steam	per cent.		10·8		15·0		9·0

TABLE 3.—*Comparative Economy of Governing by Throttling and by Variable Expansion in Double-cylinder Compound Non-condensing Portable Engines.*

Cylinders $7\frac{3}{4}$ and $11\frac{1}{2}$ inches diameter and 12 inches stroke. Boiler Pressure 135 lbs. per square inch above atmosphere.

No. of Engine	19,634	19,751	19,634	19,751	19,634	19,751	19,634	19,751
Governing by Throttle-Valve or by Variable Cut-off	Throttle.	Cut-off.	Throttle.	Cut-off.	Throttle.	Cut-off.	Throttle.	Cut off.
Initial pressure in high-pressure cylinder, above atmosphere . . . lbs. per sq. inch	128	131	113	131	87	131	63	131
Mean effective pressures from indicator diagrams: high-p. cyl., lbs. per sq. inch	43·2	46·0	40·6	44·2	30·4	40·8	23·3	34·4
Mean effective pressures from indicator diagrams: low-p. cyl., lbs. per sq. inch	33·1	33·1	25·8	22·3	18·9	12·5	12·8	5·5
Cut-off, percentage of stroke . . per cent.	60	54	60	41	60	34	60	20
Revolutions per minute . . . revs.	151·2	153·6	150·8	152·0	153·2	154·3	154·6	155·1
Indicated horse-power . . . I.H.P.	49·37	51·40	41·29	40·06	31·02	30·09	22·35	20·20
Brake horse-power . . . . B.H.P.	39·15	40·03	30·00	30·50	21·40	21·68	12·37	12·47
Mechanical efficiency, 100 × B.H.P. ÷ I.H.P. . . . per cent.	79·3	77·9	72·6	76·1	69·0	72·0	55·3	61·7
Steam consumed per indicated H.P. per hour, lbs.	22·88	21·88	22·05	21·19	24·39	23·46	28·29	26·40
Saving of steam . . . . per cent.		**4·4**		**3·9**		**3·8**		**6·7**
Steam consumed per brake H.P. per hour lbs.	28·85	28·05	30·37	27·88	35·30	32·57	51·12	42·76
Saving of steam . . . . per cent.		**2·8**		**8·2**		**7·7**		**16·4**

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TABLE 4.—*Comparative Variations of Speed in Governing by Throttling and by Variable Expansion in Single-cylinder Portable Engines.*

Cylinder 9 inches diameter and 12 inches stroke. Boiler Pressure 85 lbs. per square inch above atmosphere.

Engine No. 19,530. Throttle-Valve.	Weight suspended on brake	lbs.	254	225	196	167	138	109	80	0
	Initial pressure in cylinder, above atmosphere	lbs. per sq. inch	75	71	71	69·5	65	57	52	44
	Mean effective pressure from indicator diagrams	lbs. per sq. inch	42·7	40·0	34·9	32·8	28·0	24·8	18·3	16·2
	Cut-off, percentage of stroke	per cent.	50	50	50	50	50	50	50	50
	Indicated horse-power	I.H.P.	23·92	22·50	19·71	18·71	16·16	14·40	10·78	9·58
	Brake horse-power	B.H.P.	20·01	17·82	15·54	13·43	11·19	8·90	6·61	0
	Revolutions per minute	revs.	147·2	147·7	148·1	149·9	151·2	152·2	154·1	155·0
	Variation of speed, in percentage of lowest speed	per cent.	**0**	**0·37**	**0·66**	**1·86**	**2·75**	**3·42**	**4·7**	**5·3**
Engine No. 19,747. Variable Cut-off.	Weight suspended on brake	lbs.	254	225	196	167	138	109	80	0
	Initial pressure in cylinder, above atmosphere	lbs. per sq. inch	82	82	82	82	82	82	82	82
	Mean effective pressure from indicator diagrams	lbs. per sq. inch	41·7	37·6	31·7	30·8	27·2	24·8	21·4	19·1
	Cut-off, percentage of stroke	per cent.	40	36	34	30	27	22	16	14
	Indicated horse-power	I.H.P.	23·97	21·70	20·20	17·94	15·89	14·53	12·59	11·30
	Brake horse-power	B.H.P.	20·50	18·25	16·04	13·68	11·31	8·98	6·60	0
	Revolutions per minute	revs.	150·5	151·3	152·6	152·8	153·3	153·6	153·8	155·1
	Variation of speed, in percentage of lowest speed	per cent.	**0**	**0·53**	**1·40**	**1·53**	**1·86**	**2·06**	**2·19**	**3·06**

TABLE 5.—*Comparative Variations of Speed in Governing by Throttling and by Variable Expansion in Double-cylinder Compound Non-condensing Portable Engines.*

Cylinders $7\frac{3}{4}$ and $11\frac{1}{2}$ inches diameter and 12 inches stroke. Boiler Pressure 135 lbs. per square inch above amosphere.

Engine										
Engine No. 19,634. Throttle-Valve.	Weight suspended on brake	lbs.	486	402	346	290	234	178	122	0
	Initial pressure in high-p. cyl., above atmosphere	lbs. per sq. in.	130	113	100	94	81	64	58	40
	Mean effective pressure from ind. diagrams, high-p. cyl.,	lbs. per sq. in.	44·2	39·8	37·3	31·4	31·1	22·7	20·5	15·4
	Mean effective pressure from ind. diagrams, low-p. cyl.,	lbs. per sq. in.	36·9	29·0	24·1	19·8	17·5	15·4	11·6	6·4
	Cut-off in high-pressure cylinder, percentage of stroke	per cent.	60	60	60·	60	60	60	60	60
	Indicated horse-power	I.H.P.	50·26	44·31	38·96	33·83	30·27	24·93	20·30	13·40
	Brake horse-power	B.H.P.	39·22	32·58	28·28	23·86	19·29	14·85	10·20	0
	Revolutions per minute	revs.	151·3	152·0	153·3	154·3	154·6	156·5	156·8	159·0
	Variation of speed, in percentage of lowest speed	per cent.	**0**	**0·46**	**1·32**	**1·98**	**2·18**	**3·44**	**3·64**	**5·09**
Engine No. 19,751. Variable Cut-off.	Weight suspended on brake	lbs.	486	402	346	290	234	178	122	0
	Initial pressure in high-p. cyl., above atmosphere	lbs. per sq. in.	132	132	132	132	132	132	132	132
	Mean effective pressure from ind. diagrams, high-p. cyl.,	lbs. per sq. in.	52·1	48·4	45·8	40·6	38·2	36·3	34·8	27·3
	Mean effective pressure from ind. diagrams, low-p. cyl.,	lbs. per sq. in.	30·6	25·3	20·6	16·1	12·4	10·0	7·0	3·6
	Cut-off in high-pressure cylinder, percentage of stroke	per cent.	52·5	43	39	32	25	22	17·5	11
	Indicated horse-power	I.H.P.	49·5	43·9	38·4	32·2	27·8	25·4	21·7	16·2
	Brake horse-power	B.H.P.	38·11	32·32	27·85	23·42	19·02	14·66	10·09	0
	Revolutions per minute	revs.	148·9	150·0	150·1	150·6	151·6	153·6	154·2	155·2
	Variation of speed, in percentage of lowest speed	per cent.	**0**	**0·74**	**0·81**	**1·14**	**1·81**	**3·16**	**3·59**	**4·23**

(Mr. Frank Garrett.)

expansion is not so marked in the compound as in the single-cylinder engines. Also in single-cylinder engines the greatest advantage from variable expansion is obtained with medium loads, the advantage diminishing with either increased or decreased load; whereas in compound engines the advantage increases with the diminution of the load from the maximum.

In Tables Nos. 4 and 5 (pages 230–1) are given the comparative variations in speed under corresponding variations in load, taking in each instance the mean of three readings, each of five minutes' duration. Although in almost every case the advantage was in favour of variable expansion, still with the extreme variation in speed the advantage was not considerable. It must be admitted however that, when the load was varied suddenly, the expansion governor acted more promptly than the throttle-valve.

With respect to the relative simplicity and trustworthiness of the two modes of construction, these experiments have been made with an expansion governor of the Turner-Hartnell kind and of the simplest possible construction, acting upon a single slide-valve. This is considered by the writer to be the form of variable expansion most applicable to portable steam engines; other kinds of expansion gear, requiring double valves and much greater power to move them, are not so suitable for such small and high-speed engines. With the expansion governor and a single valve, an excellent steam-distribution is effected, almost identical in fact with that obtained in locomotives with link-motion; and the compression, which increases with diminishing loads, is an absolute advantage. In first cost there is little to choose between the two plans as employed at Leiston Works; but with respect to durability and cost of maintenance it is doubtful whether the advantage will not be found to be in favour of the throttle-valve, by reason of the diminished pressure on the slide-valve with lighter loads and its constant travel when governing by the throttle-valve. As regards regularity of rotation resulting from the mean tangential force acting upon the crank-pin, the advantage will also be with the throttle-valve, especially in a single-cylinder engine with light loads, where a comparatively heavy fly-wheel would be required for a variable-

expansion governor. For double-cylinder compound non-condensing engines the difference in this respect is not so marked; but in all compound engines a certain disadvantage accrues with very light loads, from the fact that the low-pressure piston then practically does no work—a disadvantage which is demonstrated in these trials by reduced mechanical efficiency; and with the throttle-valve governor the reduction is seen to be greater than with the variable-expansion governor.

Mr. Guy E. Lloyd wrote that, when a number of engines share a load, and work with the same initial pressure, varying the power by the cut-off, and also have a common standard consumption-curve, that is, the same consumption per I.H.P. at all loads, then the greatest economy is got when they all work at the same mean pressure. For suppose them to work in two sets: the first at a mean pressure OB, Fig. 41, Plate 34, with a value m of the factor I.H.P. $\div$ mean pressure; and the second at a mean pressure OD, with a value n of the same factor. Then the total I.H.P. $= m \times OB + n \times OD$; and the total consumption $= m \times AB + n \times CD$. Now suppose the engines to work at a common mean pressure OQ, such that $(m + n) \times OQ = m \times OB + n \times OD$. Then the total consumption $= (m + n) \times PQ$. But $(m + n) \times OQ = m \times OB + n \times OD$, or $(m + n) \times (OB + BQ) = m \times OB + n \times OB + n \times BD$; therefore $(m + n) \times BQ = n \times BD$, or $BQ = \dfrac{n}{m + n} \times BD$. In a similar manner it will be found that $P'P'' = \dfrac{n}{m + n} \times CC'$; and therefore the consumption in the first case is $m \times AB + n \times CD = (m + n) \times P'Q$. And since the curve always lies below the chord AC, PQ is always less than P'Q; that is, the consumption when all the engines work at the same mean pressure is always less than when they do not.

The following graphic construction, Fig. 42, Plate 34, shows when the addition of further engines for working a given load would lead to increased economy, in cases where the engines have a common standard consumption-curve and vary the power by the cut-off, and

(Mr. Guy E. Lloyd.)
where the efficiency of the several units is the same, and the loss constant in each, so as to be represented by a fixed mean pressure OO′. Let m be the value of the factor I.H.P. $\div$ mean pressure, with the plant as it stands; and n the value with the proposed addition. Let OA be the mean pressure in the first case, and OB in the second. Then the electrical H.P. in the first case is $m \times OA - m \times OO' = m \times O'A$; and in the second it is $n \times OB - n \times OO' = n \times O'B$. Since these are equal, we have $\frac{O'A}{O'B} = \frac{n}{m}$. Let the verticals through A and B cut the consumption curve at A′ and B′. The consumption in the first case is $m \times AA'$, and in the second it is $n \times BB'$. Draw the line A′B′P. If P falls to the right of O′, or OP is greater than OO′, then $\frac{AA'}{BB'} = \frac{PA}{PB}$ is greater than $\frac{O'A}{O'B}$ or $\frac{n}{m}$; and hence $m \times AA'$ is greater than $n \times BB'$, and the second arrangement is better than the first. Similarly, if P falls to the left of O′, the second arrangement is less economical than the first; and if P falls on O′, the two are equally economical.

Capt. SANKEY was much pleased to observe that Mr. Hudson agreed (page 220) with several of the conclusions arrived at in the paper: in regard for instance to the advantage, under certain conditions, of varying the cut-off in each cylinder; and also in regard to certain disadvantages, which, as pointed out by Mr. Raworth, are among the reasons that led to the paper being written. As regards the limit of speed for Corliss and other trip-gears, Mr. Hudson's experience is such that the author accepts at once his statement (page 220) that for large engines the maximum speed, having regard to safety and durability, is from 80 to 130 revolutions per minute. On the other hand this is no doubt a point on which manufacturers of this class of engines may well differ. For obvious reasons however it is well the maximum speed has been overstated in the paper, rather than otherwise.

As to whether throttle-governing can by careful designing be made to give sufficiently steady running under varying conditions (page 221), he can answer this question in the affirmative, and in

support would refer to Figs. 46 to 52, Plate 36, in which are reproduced some of the governing record lines. Fig. 46 is the Moscrop governing record* of a Hick Hargreaves engine of 1,000 I.H.P. working at the York Road Mill, Belfast. There can be no question that this record is excellent, and hardly likely to be improved upon. Fig. 47 is a tachograph or speed record of the same engine, and shows the same excellent result. The tachograph is an instrument similar to the Moscrop but more sensitive; it can be adjusted for any desired time-base, and in this manner changes of speed over short or long periods can be examined, and even the variation of speed during one revolution can be shown, as is the case in Fig. 48 in which the time-base is 11·7 inches per minute. Fig. 49 is the record of a two-throw Willans engine of 200 I.H.P., with cranks at 180 degrees, running at 350 revolutions per minute, and it will be conceded that the result compares well with Fig. 48; the change in speed per revolution is distinctly visible. Fig. 50 is a similar record of a three-throw Willans engine of 500 H.P., indicating 400 H.P. at the time the record was taken, and driving Messrs. Gunning and Campbell's flax mill, Belfast. In this engine the governor acts directly on the throttle-valve; but by means of a relay the cut-off is also automatically varied when a change of load occurs. These examples appear to the author sufficient to show that, as regards accuracy of governing, there is not much to choose between the two methods, when both are the best of their kind. Fig. 51 is the record of a side-by-side compound non-condensing engine, running at 140 revolutions per minute and indicating 24 H.P. when the circular saw was at work; it was governed by the cut-off, and was driving a workshop, so that the load was continually changing. Fig. 52 is the record of another engine driving a workshop, and governed by the throttle, running at 400 revolutions per minute and indicating an average of about 60 H.P. at the time the planing machine was working. Of these two examples the throttle governing was distinctly the best.

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* Published by kind permission of Messrs. Hick, Hargreaves and Co., and of the York Road Spinning Co.

(Capt. Sankey.)

In reply to Mr. Sisson the author would point out that it is unnecessary to consider secondary causes, such as compression and clearance (page 222), in order to explain the relatively smaller advantage, in respect to economy, of expansion governing at the higher initial pressure; because this effect is true for a theoretical engine, as explained in page 158 and shown in Fig. 2, Plate 20. The clearance was small in the engines whose performance is exemplified in Figs. 3 and 4, Plate 21; but the compression did not increase when the cut-off was made earlier, the two being in fact quite independent. The advantage of increasing the compression as the load diminishes was remarked upon by Mr. Sisson (page 222), and was also referred to by Mr. Garrett (page 232). In certain classes of engines the author agrees that benefit both mechanically and economically must thus be obtained. When Mr. Sisson stated (page 223) that at light loads the variable-expansion engine is affected by greatly restricted port-openings, he no doubt had in mind an engine governed by a shaft-governor acting either on the main or on the cut-off valve; and for such an engine his remarks are undoubtedly true, except at very light loads when the restriction of the ports practically causes the engine to be governed by throttling, which is actually beneficial not only for economy, as shown in page 163, but also for easy running of the engine, as pointed out by Mr. Paul (page 188). The engines with which the trials were made however had neither throttle-valve nor variable cut-off governor. Mr. Sisson's remarks cannot therefore apply to Figs. 3 and 4, Plate 21, nor do they explain the discrepancy or rather difference between the theoretical and actual consumption-lines, which is of course almost entirely due to initial condensation, and in this instance as a matter of fact was much less than usual.

The substitution of an expansion governor for a throttle governor in the rolling-mill engine referred to by Mr. Sisson (page 224) is most interesting. In the author's opinion it is a step in the right direction, and will materially increase the economy.

The trials now published by Mr. Garrett (pages 226–233) are most interesting, and the author is glad to see they agree in general with the results put forward in the paper as to the comparative gain in

governing by the cut-off. He should like however to point out that in trials of the single-cylinder engine the full load was obtained in the throttled engine with 75 lbs. initial pressure in the cylinder, and that at the same load the variable-expansion engine was working with 83 lbs. initial pressure; this was because the cut-off in the throttled engine had been fixed at 50 per cent. If the cut-off in the throttled engine had been made earlier, the full mean effective pressure of 43 lbs. per square inch would have been obtained with a higher steam-chest pressure. In this manner the throttled engine would have been made more economical at all the loads to which the trials extended, and would thus have compared more favourably with the variable-expansion engine.

As regards the tests of variation in speed, Tables 4 and 5 (pages 230–1), the result that the variable-expansion governor was slightly more accurate than the throttle governor can be accepted as conclusive only if the springs were so adjusted that each governor was just on the point of hunting: because the best governor in this respect is the one that departs least from isochronism without hunting.

THIRD REPORT TO THE ALLOYS RESEARCH COMMITTEE.

BY PROFESSOR W. C. ROBERTS-AUSTEN, C.B., F.R.S.

Molecular Porosity.—In presenting this Third Report * to the Alloys Research Committee I would remind the members of the Institution that, as so much interest was taken in the work of Professor E. Warburg and the late Herr F. Tegetmeier on molecular porosity, I was requested to repeat their observations on the electrolysis of glass.† Their original experiments were those described in the last report, ‡ and it is well for the sake of clearness to give a brief abstract of them here. A receptacle was divided by a sheet of glass, which could be several millimetres thick. Sodium amalgam was placed on one side, and pure mercury on the other; the whole was then heated to a temperature of 200° C. or 400° F., at which the glass becomes slightly conducting. By the aid of a Planté battery, the sodium atoms of the sodium silicate present were set in motion; and after the experiment had continued thirty hours it was found that a considerable quantity of sodium, amounting to 0·05 gramme or 0·77 grain, had passed into the mercury, which was originally pure. A corresponding amount of sodium had been lost by the amalgam; and the glass had exactly preserved its original weight and clearness. The glass was partly composed of neutral molecules of sodium silicate, together with free

* For First and Second Reports see Proceedings 1891, page 543; and 1893, page 102.

† E. Warburg, Über die Elektrolyse des festen Glases; Wiedemann's Annalen, vol. 21, 1884, page 622. E. Warburg and F. Tegetmeier, Über die elektrolytische Leitung des Bergkrystalls; Wiedemann's Annalen, vol. 41, 1890, page 18. E. Warburg, Über eine Methode Natrium Metall in geisslersche Röhren einzuführen; Wiedemann's Annalen, vol. 40, 1890, page 1.

‡ Proceedings 1893, page 106.

molecules both of sodium and of silica; and the free sodium was capable of being transported under the influence of the electric current. When however the sodium amalgam was replaced by lithium amalgam, the sodium of the glass passed as before into the originally pure mercury, and the glass became opaque on the side touching the lithium amalgam. After a time the opacity extended right through the thickness of the glass, and then metallic lithium began to accumulate in the previously pure mercury. It is not possible thus to chase out all the sodium present in the glass, but the free sodium atoms are replaced by those of lithium. The glass in which lithium has replaced part of the sodium is very tender, short, opaque, and friable. The conclusion is that the atoms of lithium, having an atomic weight of 7 and an atomic volume of 15·98, can pass along the tracks or molecular galleries left in the glass by the sodium atoms, the atomic weight and volume of which are 23 and 16·04 respectively. When a metal of superior atomic weight and volume to sodium is substituted for the lithium—such as potassium with atomic weight 39 and atomic volume 24—it is not found possible to chase out the sodium, the new atoms being too big to pass along through the spaces where the sodium had been. We are thus confronted with a molecular porosity which can in a sense be gauged; and the mechanical influence of the volume of the atom is thus made evident. It will also be evident that there is a direct connection between the properties of a mass and the volume of its atoms.

These remarkable results have been entirely confirmed and somewhat extended in the experiments which were undertaken in accordance with the request that was made to me. The septa, or dividing partitions, were made mostly of soda glass, of which thick bulbs were blown from barometer tube; and in most of the experiments the glass was electrolysed, using mercury and an amalgam of some metal as cathode and anode respectively. The temperature was from 250° to 350° C., or 480° to 660° F.; the electromotive force employed was 100 volts; and the current in the case of the sodium experiments averaged about one-thousandth of an ampère, and was sometimes as high as one-fiftieth of an ampère.

When thin glass bulbs were employed, they soon became cracked; and the free passage of the current fused the glass, forming a well rounded hole. In each experiment a safety fuse was placed in series, to stop the current in case of breakage.

In experiments in which sodium amalgam had been placed in the bulb and pure mercury outside, sodium passed into the mercury to the extent of 0·03 gramme or 0·46 grain. In one experiment which lasted eighteen hours the amount of sodium found in the mercury was 0·0131 gramme or 0·2022 grain. The quantity of electricity which passed through the glass was measured by the aid of an electrolytic cell placed in series, in which copper was deposited to the amount of 0·0206 gramme or 0·3179 grain. Calculating the number of coulombs of electricity passed by means of the electrolysis of glass the number 55 is found, and by the electrolysis of copper sulphate 62: thus showing, as well as a rough approximative experiment could, that the passage of sodium into the mercury follows the ordinary law of electrolysis.

It is doubtful whether the sodium from the amalgam actually penetrated right through the glass, but there can be no question that it replaced a considerable proportion of the sodium which the glass contained. An attempt to pass potassium through the same glass failed. Gold was then used, both in the form of amalgam and dissolved in metallic lead, but in the latter case the temperature employed was of course higher. No gold was found to have been transmitted through the glass; but the glass employed became coloured by gold, and minute spangles of the metal were found embedded in it. The same result was obtained when copper was used as an amalgam; and in this case minute nodules of copper were deposited below the surface of the glass, an effect which is highly suggestive in connection with the formation of mineral veins by earth currents. The terminals employed were made of platinum wire: except when copper amalgam was used, and then a copper anode was employed. Sodium amalgam placed in a bulb and surrounded with mercury, but with no current, gave negative results: showing that simple diffusion did not play any important part in the results obtained. The glass used in the

case of the sodium and potassium experiments became very tender and friable. The mere fact that a current passes at all through glass is a proof that electrolytic action has taken place: so that, even if a metal be not actually transmitted through glass, the passage of a current indicates that sodium, potassium, or other metallic constituent of the glass, must be leaving it, and is probably replaced by one or more of the metals in the metallic bath which constitutes the anode. The diagram, Fig. 1, Plate 37, will sufficiently indicate the nature of the arrangement adopted. The glass cell in which the electrolysis is effected is a test tube *a* of glass, Fig. 2, placed inside a wider tube *b*. Mercury is placed in the inner tube *a*, and the amalgam in *b*. The electrodes were of iron wire. Six such cells were placed in a cast-iron chamber C, shown in plan in Fig. 1, which was surrounded by a clay jacket D; and the whole was heated from below. A switch-board E carries six fuses *f* and mercury cups, by means of which each cell in turn could be connected with the galvanometer G.

In Fig. 3 the portion between the lines *bb* and *cc* is a section of the lead-glass, magnified twenty times, through which silver has partly penetrated by electrolytic action; it shows the singular galleries left by the decomposition of the silicate. The dendritic character *bb* of these passages, which are found on the inner or mercury side of the glass, is very interesting; while a yellow

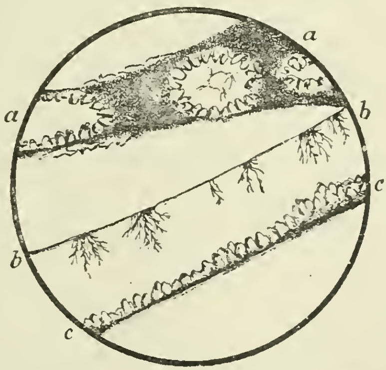

Fig. 3. Magnified twenty diameters.

stain and papilliform structure *cc* on the amalgam side of the glass indicates the depth to which silver has penetrated. The portion marked *aa* is a view of the surface of the glass, and shows the structure which is developed in it on the side nearest the amalgam.

It is not necessary to do more than state the general outcome of the work, as the experiments, notwithstanding their great interest, can be considered only to be incidental to the main investigation of the Committee, the object of which is to ascertain how far the mechanical properties of metals are in accordance with the "periodic law" of Newlands and Mendeléeff (Proceedings 1893, page 102). I consider however that the results obtained by Professor Warburg have been abundantly confirmed.

When the Second Report was published, the work of the Committee had entered upon a delicate and critical stage. Copper formed the main subject of investigation, and the evidence obtained in connection with it was conflicting. It was proved that bismuth, potassium, and tellurium—all of which have large atomic volumes—lower the tenacity of copper. Arsenic, which has a larger atomic volume (13·2) than copper (7·1), confers strength on copper; but it appeared that the limit of elasticity and the ductility of metals generally are greatly influenced by the presence of such of the elements which have thus far been studied as possess large atomic volumes; and this fact may be of more molecular significance than the diminution of tenacity, to which, for the sake of simplicity, attention was mainly directed when the early experiments on gold were made.

In continuing the work, a series of tests were made on iron-aluminium, copper-nickel, and copper-zinc alloys, as well as those alloys which are more particularly described in the appendices to this Report. The iron-aluminium alloys presented many points of interest, to which allusion will be made.

Increased Sensitiveness of Pyrometer.—It soon became evident that the recording pyrometer described in the last Report, which is entirely the result of the labours of the Committee, is a powerful

instrument of research. It affords the most hopeful method of continuing the investigation entrusted to me. It was necessary however to increase the sensitiveness of the instrument. This was readily effected, and the nature of the changes which were adopted will be clear by reference to the drawings of the recording pyrometer given in Plates 28 to 30 of the previous Report (1893). These drawings show that the galvanometer, which affords the means of measuring the temperatures of the masses of metal or alloy under examination, may occupy one of two positions: it may either be nearer to the slit through which the ray of light falls upon the photographic plate, or it may be further away from it. It will be evident that, as shown in the rough plan, Fig. 4, Plate 37, two galvanometers A and B may be used simultaneously, with the light from their respective mirrors playing through the same slit S upon the photographic plate P. The further galvanometer B can have a much lower resistance, and consequently greater delicacy, than the nearer one A: so that, while the line photographed on the moving sensitised plate from the nearer galvanometer A might represent a range of temperature of say 1,500°, the line traced by the mirror of the further galvanometer B should represent only one-tenth of this. The angular deflection of the nearer mirror A would not exceed the limits of the sensitised plate P, while the mirror of the delicate galvanometer B might traverse a far larger range. Both galvanometers would be connected "in parallel" with the same thermo-junction J; and obviously any portion of the extended range which it was desirable to reflect on the sensitised plate could easily be caught by a suitable adjustment of the mirror on the further galvanometer B. If therefore the thermo-junction J is plunged into a mass of metal cooling from say an initial temperature of 1,500°, the whole of the cooling curve could be traced by the mirror of the less delicate galvanometer A, while only a portion greatly magnified would be recorded by the mirror of the more delicate galvanometer B. The first curve derived from galvanometer A would serve as a "calibration curve" for that afforded by galvanometer B. By this method some remarkable results have been obtained.

Cooling Curve of Electro-Iron.—In Fig. 6, Plate 38, is given a curve for electro-iron, prepared by depositing iron from chloride of ammonium and iron, the iron so deposited being used as an anode for re-depositing the iron on a slip of fusible metal, which was afterwards simply melted away at a low temperature from the iron deposited. No carbonate had been used in neutralising these solutions subjected to electrolysis. A rigorous search was made for carbon in the iron, without its being possible to detect the presence of even a trace. The curve, copied from an untouched photograph obtained by the delicate method of recording just described, indicates Osmond's highest point of recalescence Ar3, which is due to the evolution of heat that occurs at 832° C. or 1,530° F. in this electro-iron, as it cools down from an initial temperature of some 1,200° C. or 2,200° F. The second curve on this diagram shows that Osmond's point Ar2 could just be detected at about 721° C. or 1,330° F. in this specimen of iron; but the lowest point of recalescence Ar1 was absent. (See Proceedings 1893, page 155, footnote.) These curves are merely given as an illustration of the method; and it is not my intention here to enter into the question of allotropy of iron, which has been fully discussed elsewhere. It will, I trust, be evident that this new method of investigation renders it possible to obtain information as to what is happening in the midst of a mass of metal from the moment it begins to cool until it is solid, and even after it has become solid.

An examination of the cooling curve of standard gold, to which a small amount of bismuth has been added, is even more remarkable. The presence of 0·2 per cent. of bismuth causes standard gold to be so brittle that it may be broken readily between the fingers. Fig. 7, Plate 39, in which is traced a sensitive curve of cooling standard gold, shows that bismuth, probably associated with a small amount of gold, solidifies at the very low temperature of 228° C. or 442° F. It is possible to fix the exact temperature of this point by throwing upon the same plate the cooling curves of pure bismuth and of pure tin, which are also shown in Fig. 7. It will be seen that in each case the singular phenomenon of "surfusion" is well marked—

that is, the property of cooling below the freezing point before actually becoming solid. The fact is thus revealed, which has long been suspected, that, although only a very small quantity of an element be hidden in a mass of metal, this small quantity can make its influence felt; for it appears to remain free, or to associate itself with but few atoms of the mass in which it is hidden. The significance of these facts will be considered later.

Cooling Curve of Aluminium-Copper Alloy.—In Fig. 8, Plate 39, is given the cooling curve of an alloy of aluminium, the metal which has excited so much interest in connection with naval construction. It is the cooling curve of the aluminium-copper alloy, containing 6 per cent. of copper, of which a torpedo-boat has recently been constructed for the French government by Mr. Yarrow, to whom I am indebted for a specimen of the alloy. The main mass sets at a temperature of 620° C. or 1,150° F.; but the copper associated with the aluminium gives a second lower freezing point at 515° C. or 970° F. Now compare this with the alloy of aluminium which contains 30 per cent. of nickel. Here the nickel, doubtless in association with some aluminium, freezes before the main mass; and this alloy is found to be considerably stronger than the other.

Iron-Aluminium Alloys.—The pyrometric examination of this series of alloys was undertaken in view of the increasing importance of the latter metal; and although no alloy of industrial importance was discovered, much insight has been afforded as to the general behaviour of aluminium when alloyed with other metals. In preparing the alloys an attempt was made to exclude carbon as far as possible, so that cooling curves might be obtained of alloys consisting simply of iron and aluminium. On this account the iron and aluminium were melted in a clay crucible in a furnace heated with coal gas burnt by oxygen, arranged as in Fig. 5, Plate 38, a layer of glass being added to protect the alloy from oxidation. The composition of each sample was determined subsequently. The

furnace was arranged with an inner lining of fire-clay tiles, round which the flame circulated before escaping; and the thermo-couple, enclosed in a fire-clay tube and previously heated in the upper part of the furnace, was thrust through the hole *h* into the liquid alloy directly after turning off the gas. With this furnace very high temperatures could be attained, and little heat was lost during the insertion of the thermo-couple: so that after a little practice most of the cooling curves of this series were obtained with facility. As the amount of iron in the alloy is increased, the temperature of the melting point rises. With alloys containing as much as 90 per cent. of iron, and with iron itself, the method had to be modified, because the thin crucible, although of refractory fire-clay, melted down. The solid base of a larger crucible was bedded upon the floor of the furnace, so as to form a shallow dish, in which the iron or the alloy was placed, the flame passing over and heating the metal directly. By this means cooling curves of iron, which was practically free from carbon, were obtained to complete the series. The heat was so intense that the fire-clay tube enclosing the thermo-couple often became quite soft and bent while it was being placed in the metal, which of course increased the difficulty of manipulation.

Inspection of a selection of the cooling curves given in Fig. 9, Plate 40, which are arranged in the manner described in the appendix, page 270, shows that their general nature resembles that of the copper-bismuth alloys dealt with in the Second Report, 1893, page 122, and Plate 32. They are much simpler than the copper-tin series in the appendix, page 270, and Fig. 10, Plate 41. The freezing points of the several alloys lie on two lines: a line *bb*, which passes through the melting point of aluminium, and is nearly horizontal; and a curved line *aa*, which passes through the melting point of iron.

It will be seen that the freezing point of iron alloyed with say one per cent. of aluminium is but little lower than that of iron itself: that is to say, the melting point of nearly pure iron is only slightly lowered by a small addition of aluminium. Osmond has already shown that aluminium does not produce any considerable lowering of the freezing point of cast-iron; and the usually accepted idea that

cast-iron or steel containing aluminium is very fusible must be due to the fluidity of the metal when it is melted.

Alloys of iron and aluminium which contain from 20 to 35 per cent. of iron show two freezing points, Fig. 9, Plate 40, the lower occurring at a constant temperature, a few degrees below the freezing point of pure aluminium. Alloys which contain more than 35 per cent. of iron have only one freezing point. Alloys containing 40 to 50 per cent. of iron solidify within a very small range of temperature, the temperature of the mass of metal falling only slightly during the change from the liquid to the solid state. Alloys containing more than 50 per cent. of iron have a more extended freezing range, the temperature of the mass sometimes falling as much as 100° C. or 180° F. during its solidification, as will be evident from the slope of their cooling curves. A curve of this kind indicates that a series of small portions of the alloy, having successively lower and lower freezing points, and therefore containing more and more aluminium, are becoming solid. A cooling curve which is flat within the freezing range indicates that all the metal which then solidifies freezes at the same temperature, and has therefore probably a uniform composition; and in some cases indicates the presence of a chemical compound rather than a mere solution. The freezing range is most restricted in the alloy containing about 50 per cent. of aluminium.

The samples of alloys used in these experiments were kept for some months before being analysed; and it was found that during this time those which contained from 40 to 60 per cent. of aluminium had spontaneously disintegrated, and had fallen to powder. The powder was not oxidised, but consisted of clean metallic grains, probably resulting from chemical changes which had gradually taken place in the solid alloy. Whether the iron and aluminium were in a state of solution or were chemically combined when molten, there can be little doubt that they are so combined in the metallic powder, as attempts to re-melt this powder have proved unsuccessful, which points to the formation of an infusible compound. Solutions are considered to be dissociated chemical compounds. These two metals, iron and aluminium, may have been too hot to unite

when in the molten state; but at a lower temperature long-continued proximity at last effected their chemical union. It will hardly be supposed that this is an isolated case in the study of alloys. The allotropy or molecular change which takes place in Newton's fusible alloy when solid has already been cited (Second Report, 1893, page 127); and no doubt many unaccountable changes in alloys, leading to unforeseen fracture and disaster, are traceable to the same cause. The fusible alloys which are used in automatic appliances for extinguishing fires, and in certain cases for safety plugs, undergo a molecular change of this kind, which renders them much more infusible than when freshly made; and the alloys of lead and tin melt in general at temperatures considerably above those at which they freeze.

The iron-aluminium alloy which disintegrates most completely in this way contains about 50 per cent. of iron, so that the powder may be a compound having the formula $Fe\,Al_2$; but as it appears to be able to dissolve a small excess of either metal, it is not possible directly to confirm this view without further investigation. The iron-aluminium alloys which contain more than 60 per cent. of iron have higher melting points, and become stronger, as the amount of iron is increased; those containing about 90 per cent. of iron appear to be tough and strong. [See page 297.] They also appear to freeze at a higher temperature than iron itself: although, in view of the difficulty of obtaining cooling curves from the more infusible alloys, it would be well to confirm this point.

Tensile tests of these alloys have not yet been made; but it seems likely that some alloy of aluminium with iron free from carbon, containing about 90 per cent. of iron, might prove a highly serviceable material for the production of small malleable castings of considerable strength. Most of the iron-aluminium alloys are rendered worthless for industrial application by their liability to undergo molecular change, which is so marked in the alloy containing 50 per cent. of each metal.

Welding of Iron and Steel.—The following experiments were made by Mr. Thomas Wrightson, M.P., with the object of

ascertaining whether the welding of iron is attended with a fall of temperature, as is the case in the regelation of ice. After some preliminary experiments, it was decided that the only satisfactory way of testing this would be by means of the electric welding apparatus of the Thomson-Houston Co., in which alternating currents are employed. The Electric Welding Co. readily put at our disposal one of their excellent appliances and a suitable dynamo. The manager Mr. Armstrong, and the electrician Mr. Relf, assisted in installing these at the Mint, and rendered every possible assistance in making the arrangement effective. The leads were carried to my laboratory from the Mint dynamo room, where, by the kindness of Mr. Robert A. Hill, superintendent of the Operative Department, the alternating dynamo was placed, and was driven from the Mint engines. In Plates 80 and 81 of last year's Proceedings (1894) is shown the general arrangement of the electric welder.

The thermo-junction was placed between the clean surfaces of the rods of iron to be welded; and these rods were enclosed in a porcelain tube contained within a suitable jacket of iron, as shown in the sketch Fig. 14, Plate 44. The object of the electric welder was merely to raise the iron to a temperature at which it could be welded; and when this temperature was obtained, pressure was applied, and a photographic curve was traced, which would of course indicate any variation of temperature that might ensue upon the application of the pressure. The pressure was applied when the temperature of the rods was about 1,300° C. or 2,370° F. A slight rise of temperature was at first noted, and this was found to be due to the fact that the interstices between the outside of the rod and its insulated envelope had not been entirely filled by the plastic iron. The porcelain of course cracked, and the minute cracks had also to be filled by the plastic iron before the effect of pressure in producing a fall of temperature could be demonstrated. After reheating the rod to the welding heat, it was again compressed at a temperature of about 1,400° C. or 2,550° F., and a fall of temperature was shown, equal to about 57° C. or 106° F. These experiments were repeated many times, and appeared to show that the application of pressure to plastic iron, heated within the range of temperature

at which it could be welded, is certainly attended by a fall in temperature. The welding of iron and the regelation of ice would thus appear to be analogous phenomena, a point of no small theoretical importance. These results have already been communicated by Mr. Wrightson to the Royal Society; and it would have been impossible to obtain them, had not the recording pyrometer been available.

Anti-friction Alloys.—The work of the Committee has been fruitful in a somewhat unexpected way; for Professor Goodman informs me that experiments, the results of which I trust he will communicate to the Institution, have led him to discover the fact that anti-friction alloys must always contain a metal with a high atomic volume. There seems moreover to be a direct connection between the efficiency of the anti-friction alloy and the atomic volume of one of its constituents.

Conclusions.—In the last Report I called attention to the fact that M. André Le Chatelier had suggested that the prejudicial action of an element is due to its forming a fusible compound with the metallic mass in which it is hidden; while on the other hand the presence of an element which forms an infusible compound with the mass promotes the formation of a fine grain, and imparts strength. It must not be supposed however, as I then pointed out, that the action of the added element is due solely to its infusibility, or to its power of forming a fusible compound with a portion of the mass which contains it; for cases are numerous in which such an explanation does not apply. In this connection a suggestion made long ago by Raoult Pictet * well deserves consideration. He urged that there must be a connection between the melting points of metals and the periodic law of Mendeléeff; for he showed that for all metals there is a simple relation between their atomic weight, the amplitude of the movement of their molecules under the influence of heat, and their melting point. Pure metals with high melting

* Comptes Rendus, vol. 88, 1879, pages 855 and 1315.

points—such as platinum, iron, copper, and gold—are comparatively strong; and conversely metals with low melting points—zinc, lead, cadmium, bismuth, and tin—are relatively weak. Metals with high melting points must necessarily be coherent and tenacious, because much *heat* is required to drive their molecules apart in reducing them to the liquid mobile state in which the molecules have very small coherence; and therefore at ordinary temperatures much *force* must be applied to overcome the cohesion of the molecules and break the mass. Conversely in metals with low melting points a small elevation of temperature will overcome the molecular cohesion, and render them liquid—that is, will melt them. Such metals will be weak, because if little heat is required to melt the metal, less force will be needed to tear it apart. Hence melting point and tenacity are clearly connected.

The absolute temperature of the melting point of a metal must be closely connected with its *atomic volume*, because the former is inversely proportional to the rate at which the amplitude of the oscillations of the molecules increases with temperature; and the rate of increase of amplitude at any given temperature is obtained by multiplying the ordinary thermal coefficient of linear expansion by the cube root of the atomic volume.*

The recent work of Professors Dewar and Fleming † bears directly on this question. They employed very low temperatures, and show that at the absolute zero of temperature pure metals would probably offer no resistance to the passage of an electric current, but that the electrical resistance of alloys does not diminish so rapidly with the lowering of temperature as in the case of pure metals. Dewar‡ has shown moreover that the tenacity of pure metals and alloys is greatly increased by extreme cold, that is, by the closer approximation of their molecules: and this affords additional evidence that metals become stronger at temperatures which are further and further removed from their melting points.

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* Pictet, Comptes Rendus, vol. 88, 1879, page 856.

† Philosophical Magazine, vol. xxxiv, 1892, page 326.

‡ Proceedings of the Royal Institution, vol. 14, part 2, 1895, page 1.

The experiments on the alloys of copper and tin, as well as a series of cooling curves of the copper-nickel alloys, which have only been alluded to in this Report, have direct bearing on the view that there is an intimate connection between the melting point of an alloy and its mechanical properties. This connection, which is well marked at ordinary temperatures, becomes of great importance in the case of alloys that have to be subjected to more or less heat in industrial use. The majority of alloys, as has been shown, have more than one solidifying point; and it is necessary to ascertain which of these freezing points is the important one in relation to the mechanical properties of the alloy. In copper containing bismuth, or in gold containing either bismuth or lead, the presence of a trace of such a metal with a large atomic volume and consequently low melting point renders the mass intensely brittle, and quite unfits it for mechanical use. Great weakness is here associated with the low subsidiary freezing point of a mass which is nevertheless as a whole fairly infusible. The action however of traces of impurities on masses of pure metals is very different from the effect of two metals on each other when alloyed in more or less equal proportions. In the latter case the temperature of the main freezing point appears to be the more significant factor; the presence or absence of lower subsidiary freezing points seems to be of much less importance. At present therefore attention is directed to ascertaining the relation between the low subordinate solidifying point and the mechanical properties of metals which contain small quantities of impurity. It appears that in such metals a low subordinate freezing point is usually associated with small tenacity. The increased sensitiveness which has now been given to the recording pyrometer renders a solution of this complex problem more hopeful.

The investigations printed in the Appendices, though lying a little beyond the lines laid down by the Committee, have nevertheless a direct bearing on their work as a whole. The researches conducted by Mr. Stansfield and by Mr. Allan Gibb were in each case undertaken on my suggestion as a thesis for the "Honours" Associateship in Metallurgy of the Royal School of Mines.

Mr. Gowland has rendered valuable assistance to the Committee by his guidance and advice in connection with Mr. Gibb's paper.

Since Mr. Stansfield's appendix was printed (pages 269–279), experiments have been made in the direction he indicated, with a view to obtain more exact information as to the constitution of the copper-tin and other series of alloys. Those which have only two freezing points, as is the case with the copper-bismuth and silver-lead alloys, appear to be closely analogous to ordinary salt solutions: the upper freezing point, occurring at a comparatively high temperature which increases with the percentage of the less fusible metal, represents the beginning of the crystallisation, in a nearly pure state, of this less fusible constituent; the lower point, which occurs at the same temperature throughout each particular series, represents the freezing of the eutectic alloy—a mutual solution of the two metals which is more fusible than any other admixture. A full explanation of the copper-tin and other alloys of more complicated character has not yet been obtained; and the views expressed in Mr. Stansfield's appendix will probably require amplification.

I cannot conclude this Report without expressing my warm appreciation of the excellent services which Mr. Stansfield has rendered in aiding me in conducting the tedious experiments, the results of which are now submitted to the Institution. Mr. Reginald Roberts, who was appointed as an assistant early last year, has also done good work.

For Discussion see page 280.

APPENDIX 1 TO THIRD REPORT TO THE ALLOYS RESEARCH COMMITTEE

THE ELIMINATION OF IMPURITIES DURING THE PROCESS OF MAKING "BEST SELECTED" COPPER.

By Mr. ALLAN GIBB, Associate of the Royal School of Mines.

In the Welsh method of Smelting Copper the earlier operations concentrate the copper into a compact "matte" or "regulus," known in smelting works as "white metal," which in composition approximates to copper disulphide, Cu_2S. For the manufacture of ordinary commercial copper, the "white metal" is roasted completely to produce "blister" copper, by exposing it whilst melting, and after it is molten, to the action of a strongly oxidizing atmosphere in a reverberatory furnace. This roasting process however may be stopped when any fractional part of the total copper in the "white metal" is reduced to the metallic state; and if the furnace charge is then tapped into moulds, some or all of these will be found to contain pigs consisting of two layers, the upper being a regulus of vesicular structure, known as "spongy regulus," while the lower layer is metallic copper, known as "bottoms." This partial reduction of the copper in "white metal" is the essential feature in the process of making "best selected" copper.

A modification of this process has also been followed, in which the furnace charge consisted not of white metal only, but of a mixture of oxides and sulphides of copper with coal. By the reducing action of the coal, varying quantities of metallic copper were separated and obtained as above, as copper bottoms covered with a layer of regulus.

Both of these methods are described by Dr. Percy, in his account of the early practice followed for the manufacture of "best selected" copper, taken from a manuscript dating from about 1743. According to Le Play both were still practised in 1848; but the last method

seems to have fallen into disuse in more recent times. For the production of "best selected" copper, which is the highest quality of copper that can be obtained by the Welsh process, the partial reduction of white metal, with the formation of spongy regulus and copper bottoms, has been extensively practised by copper smelters, for the reason that the spongy regulus was found to yield a purer copper than was obtained when the white metal was completely roasted to produce "blister" copper.

Impurities.—The foreign metals which occur in copper ores, and which have the most deleterious effects on the properties of the metal when it is used for making alloys that have to be rolled into sheets or drawn into tubes, &c.—such as the alloys of the copper-zinc series—are tin, antimony, bismuth, and arsenic. During the operations of smelting, all these metals to a greater or less extent pass into the white metal; and when it is roasted completely, so that the whole of its copper is reduced, they are found in large proportions in the copper so obtained. When however the white metal is treated by the process of partial reduction already mentioned, these metals concentrate in the copper bottoms, and the spongy regulus is proportionately freed from them. The whole amounts present of these metals do not pass into the bottoms; for, although their sulphides are all decomposed with more or less completeness by fusion with metallic copper, yet they all form double sulphides with copper disulphide; and it has not been found possible to decompose thoroughly these double compounds in the presence of excess of this disulphide, even when fused with a large quantity of metallic copper. Hence, although on the large scale the proportion of copper reduced is large compared with the amounts present of these metals, their separation from the accompanying regulus is but fractional. In this research an attempt has been made to determine with some exactness the relative degrees to which these metals are separated from the regulus and concentrated in the bottoms. To that end, samples were taken from the products of the following operations on the large scale, and also of comparatively small experimental fusions in the laboratory:—

Actual smelting operations in reverberatory furnaces.
" " " " cupolas or blast furnaces.
Fusions in crucibles in the laboratory.

The reason why samples were taken from blast-furnace operations was that the conditions which prevail in them are analogous to those of the process in which carbon was formerly used as the reducing agent. In the reverberatory-furnace samples, the proportions of copper reduced and separated as bottoms were 8·2 and 16·0 per cent. of the total copper in the charge, Table 5, Nos. 1 and 4; while those from the blast-furnace formed 47·5 and 54·5 per cent., Nos. 15 and 16. In order to fill up the wide gap existing between the percentages of bottoms from the reverberatory furnace and those from the blast furnace, it was necessary to make experimental fusions in crucibles, in which other and intermediate proportions of copper could be separated. A fairly complete series was thus obtained. The samples were all carefully analysed, and the analyses are given in Table 5, pages 261–5.

In Table 5 are shown the percentages of copper and other metals in the spongy regulus and in the copper bottoms, and the corresponding percentages on the copper. In Table 6 and diagram Fig. 21, Plate 46, is shown the percentage of the several contaminating metals that is concentrated in the bottoms, when various percentages of the total copper are separated in that form. In Table 7 and diagram Fig. 22, Plate 47, is shown the relative impurity of the copper remaining in the spongy regulus, and of the copper before the separation of bottoms. From these tables and diagrams it will be seen that, when white metal is treated by the partial reduction process for the production of bottoms, the metals above enumerated—namely tin, antimony, bismuth, and arsenic—are not all concentrated in the bottoms to the same degree, even under similar conditions. The behaviour of each will therefore be considered separately.

Tin.—The concentration of foreign metals in copper bottoms is most marked in the case of tin. As this metal was absent from all the samples taken from actual smelting operations, as well as

from those produced in the laboratory from furnace materials, tin sulphide was added to a regulus made by fusing electrotype copper with sulphur; and the mixed sulphides were fused with oxide of copper, Table 5, No. 8. The fusion produced 107 grammes regulus and 22·7 grammes bottoms. The regulus contained 80·02 per cent. copper and 0·03 per cent. tin; the bottoms contained 97·62 per cent. copper and 2·01 per cent. tin. Thus 20·6 per cent. of the total copper was reduced; and it contained 93·4 per cent., Table 6, and the accompanying regulus only 6·6 per cent., of the total tin present in the original mixture.

Antimony.—Antimony is next to tin in the completeness of its concentration in the bottoms. When 8·2 per cent. of the total copper was reduced, 21·0 per cent. of the total antimony was found with it in the bottoms, Tables 5 and 6, No. 1; and diagram Fig. 21, Plate 46. This proportion rises to 80·8 per cent. of the total antimony, when 17·3 per cent. of the total copper is separated, No. 5. From this point the proportion of antimony which concentrates in the bottoms does not increase much with an increase in the amount of copper separated, only reaching 93·7 per cent. of the total antimony when 47·5 per cent. of the total copper is separated as bottoms, and actually receding to 92·6 per cent. antimony with 54·5 per cent. copper, Nos. 15 and 16. Intermediate results are given in Nos. 4, 12, and 13.

Bismuth.—In Table 6, Nos. 1 and 4, it will be seen that, with a separation of 8·2 and 16·0 per cent. of the total copper as bottoms, 11·1 and 43·1 per cent. respectively of the total bismuth passes into the copper bottoms, Fig. 21, Plate 46. There is hardly any further increase in the concentration of the bismuth with any increased proportion of copper reduced. Thus in No. 15, when 47·5 per cent. of the total copper is separated as bottoms, only 47·6 per cent. of the total bismuth is found in them.

Arsenic.—The proportions of the total arsenic which concentrate in bottoms are 21·5 and 30·6 and 60·2 per cent. respectively, when

8·2 and 16·0 and 25·2 per cent. of the total copper is separated in that form, Table 6, Nos. 1, 4, and 9; and diagram Fig. 21, Plate 46. Arsenic thus differs from bismuth in the rate of its elimination from the main bulk of the copper. With 8·2 per cent. of the copper as bottoms, a larger proportion of arsenic than of bismuth passes into them; while with 16 per cent. the proportion of bismuth concentrated in them is greater than that of arsenic. But at the latter point the concentration of the bismuth has practically reached its maximum; whilst in the case of arsenic this is only attained when 34·7 per cent. of the total copper is reduced, No. 13.

In all the experiments considered thus far, the proportions of the contaminating metals are small, but are such as are found in the furnace materials commonly treated in British smelting works. The presence of large proportions of some metals often affects notably the concentration of others; a marked example is afforded by the behaviour of the metal nickel when it occurs along with arsenic.

Nickel, and Nickel with Arsenic.—When present alone, nickel does not appear to concentrate in bottoms. Only 8·0 per cent. of the total nickel is found in them when they contain 8·2 per cent. of the total copper, Table 6, No. 1. But when arsenic occurs together with nickel, as in Nos. 7 and 11, and both are present in high proportions, they concentrate largely in the separated copper. Thus with a separation of 19·3 per cent. of copper as bottoms, 77·7 per cent. of the total arsenic and 47·9 per cent. of the total nickel are found in them, No. 7; and when 28·3 per cent. of copper is reduced, 83·9 per cent. of the total arsenic is concentrated in it, No. 11. This is not contrary to expectation, in view of the well-known practice of concentrating nickel in a speise (that is, a combination of arsenic or antimony with iron, copper, nickel, &c.). The materials in these experiments contained silver; and it is worthy of note that its concentration is lessened by the presence of arsenic and nickel, as seen in the diagram Fig. 21, Plate 46.

The concentration of gold and silver in copper bottoms has also been determined, although this hardly comes within the scope of the

title of this paper; for when these metals are present in proportions large enough to affect the mechanical properties of copper, their value is sufficiently great to necessitate other and special methods for their extraction. As however gold and silver were both present in the materials of the other experiments, it was thought a matter of interest to ascertain to what extent they could be separated from the regulus and concentrated in the bottoms of the "best selected" process. The concentration of gold in bottoms has been and is carried on as a means for its extraction from copper ores; but the concentration of silver is not sufficiently complete to render this process applicable for its separation.

Gold.—The results given in Table 6, Nos. 1 and 3, show that, with a reduction of 8·2 per cent. of the total copper as bottoms, they contain 41·5 per cent. of the total gold; whilst when 14·4 per cent. of the copper is reduced to bottoms, the whole of the gold is found in them. In some cases traces of gold remained in the regulus; but they were too small to be weighed, even when 50 grammes of the samples were taken for assay.

Silver.—Silver nearly reaches its maximum concentration in bottoms when 19 per cent. of the total copper is separated in this form, 42·9 per cent. of the total silver being then contained in them, Table 6, No. 6.

Effect of Metallic Iron on the Concentration of Metals.—The addition of metallic iron during the separation of metals from a copper regulus and their concentration in bottoms was the subject of a special experiment. Metallic iron completely decomposes the sulphides of antimony, lead, and silver; but when these are present in the complex sulphides produced in lead smelting, their complete separation is not possible; and although iron reduces copper from the higher sulphides produced in the Welsh process of copper smelting, its action is gradually lessened with the increasing proportion of iron sulphide thereby formed. Copper sulphide with which had been melted sulphides of lead, antimony, silver, and gold, was remelted with an excess of iron. The proportion of total copper

separated as bottoms was 35·0 per cent., Table 6, No. 14; and in it were concentrated—

74·5	per cent.	of	the	total	silver
83·5	,,	,,	,,	,,	lead
97·0	,,	,,	,,	,,	antimony
92·8	,,	,,	,,	,,	gold

There is a notable increase in the proportions of antimony and silver concentrated in the bottoms, when compared with those in the experiments previously considered in which iron was not used.

Conclusions.—From the experimental results given above and in the tables the following conclusions may be drawn. Of the four metals—tin, antimony, arsenic, and bismuth—tin is concentrated in the bottoms in the highest degree, antimony approaches tin in this respect, arsenic is concentrated in smaller proportions, and bismuth scarcely at all. Thus it is seen from Table 6 and Fig. 21, Plate 46, that, when about 20 per cent. of the total copper in "white metal" is separated as bottoms by partial reduction, the copper obtained by roasting the remaining spongy regulus will contain about 90 per cent. less tin and about 80 per cent. less antimony—and, when 25 per cent. of copper is separated, about 60 per cent. less arsenic—than the copper which would have been produced by roasting the white metal completely. In regard to bismuth, the copper produced from the spongy regulus, when 16 per cent. of the total copper has been separated as bottoms, will contain only about 43 per cent. less bismuth than the copper which would have been obtained by complete roasting. The purifying effect of the separation of bottoms in the removal of antimony from the spongy regulus is but little increased when a larger proportion of copper than 20 per cent. is thus separated; and in the removal of arsenic and bismuth the increase not only almost ceases when 25 per cent. and 16 per cent. respectively of copper are separated, but the purifying effect as regards arsenic is actually lessened when more than 35 per cent. of copper is separated as bottoms.

concluded on page 268.

TABLE 5 (*continued to page 265*).—*Summary of Results of Analyses.*

Percentages of Copper in Copper Regulus and Copper Bottoms; and corresponding percentages† on Total Copper.*

No. of Sample.	Description of Sample.	Products of Fusion.		COPPER.			
		Weight of Regulus.	Weight of Bottoms.	Percentage in Regulus.	Percentage in Bottoms.	Percentage on Total Copper. Regulus.	Percentage on Total Copper. Bottoms.
No.		Tons.	Tons.	Per cent.	Per cent.	Per cent.	Per cent.
1	Reverberatory Furnace, 1st sample . .	56·262	3·975	77·36	97·83	91·8	8·2
		Grammes.	Grammes.				
2	Experiment with Bismuth	470	35	70·40	96·01	90·4	9·6
3	Matte and Cupric Oxide	210	29	78·92	96·54	85·6	14·4
		Tons.	Tons.				
4	Reverberatory Furnace, 2nd sample . .	5·498	0·795	74·45	97·63	84·0	16·0
		Grammes.	Grammes.				
5	Experiment *b*	123·3	20·0	73·10	94·37	82·7	17·3
6	Experiment *d*	110·4	20·7	80·31	99·95	81·0	19·0
7	Matte with Arsenic and Nickel, 1st sample .	219	49	66·56	71·31	80·7	19·3
8	Experiment *g*	107	22·7	80·02	97·62	79·4	20·6
9	Experiment *e*	115·2	28·9	70·32	94·48	74·8	25·2
10	Matte with Arsenic and Nickel, 2nd sample	127	37	59·68	74·62	73·3	26·7
11	,, ,, ,, ,, ,, 3rd sample	127	40	60·86	76·25	71·7	28·3
12	Matte	128	35	57·86	87·80	70·7	29·3
13	Matte	128	42	59·29	96·03	65·3	34·7
14	Experiment *c* with Lead and excess of Iron	102	49·3	68·88	76·74	65·0	35·0
		Tons.	Tons.				
15	Cupola, 1st sample	8·629	5·632	69·34	96·35	52·5	47·5
16	Cupola, 2nd sample	8·501	6·967	68·88	97·41	45·5	51·5

* Thus in No. 1 the Copper remaining in the Spongy Regulus constitutes 77·36 per cent. of the entire weight of the regulus; and that separated in the Bottoms constitutes 97·83 per cent. of the entire weight of the bottoms.

† Thus in No. 1, 91·8 per cent. of the entire Copper remains in the Spongy Regulus, and 8·2 per cent. is separated in the Bottoms.

TABLE 5 (*continued from preceding page*).—*Summary of Results of Analyses.*

Percentages of Arsenic and Antimony and Nickel in Copper Regulus and Copper Bottoms; and corresponding percentages † on Copper.*

No. of Sample.	Description of Sample.	ARSENIC. Percentage in Regulus.	ARSENIC. Percentage in Bottoms.	ARSENIC. Percentage on Copper. Regulus.	ARSENIC. Percentage on Copper. Bottoms.	ARSENIC. Percentage on Copper. Total.	Sb = ANTIMONY. Ni = NICKEL. Percentage in Regulus.	Sb = ANTIMONY. Ni = NICKEL. Percentage in Bottoms.	Sb = ANTIMONY. Ni = NICKEL. Percentage on Copper. Regulus.	Sb = ANTIMONY. Ni = NICKEL. Percentage on Copper. Bottoms.	Sb = ANTIMONY. Ni = NICKEL. Percentage on Copper. Total.
No.		Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
1	Reverberatory Furnace, 1st sample . .	0·058	0·231	0·075	0·236	0·088	Sb 0·033 Ni 0·285	Sb 0·118 Ni 0·360	Sb 0·043 Ni 0·368	Sb 0·121 Ni 0·368	Sb 0·050 Ni 0·368
2	Experiment with Bismuth										
3	Matte and Cupric Oxide						Sb	Sb	Sb	Sb	Sb
4	Reverberatory Furnace, 2nd sample . .	0·187	0·571	0·249	0·584	0·303	0·033	0·432	0·044	0·442	0·108
5	Experiment *b*						0·043	1·121	0·059	1·188	0·254
6	Experiment *d*										
7	Matte with Arsenic and Nickel, 1st sample	0·70	10·91	1·05	15·30	3·70	Ni 2·52	Ni 10·34	Ni 3·79	Ni 14·50	Ni 5·86
8	Experiment *g*										
9	Experiment *e*	0·101	0·72	0·141	0·762	0·31					
10	Matte with Arsenic and Nickel, 2nd sample	0·52	7·74	0·870	10·38	3·48					
11	,, ,, ,, ,, ,, 3rd sample	0·42	6·92	0·690	9·08	3·06	Sb	Sb	Sb	Sb	Sb
12	Matte						0·0045	0·112	0·0077	0·128	0·043
13	Matte	0·092	0·555	0·151	0·578	0·30	0·006	0·140	0·010	0·146	0·057
14	Experiment *c* with Lead and excess of Iron						0·014	0·952	0·021	1·241	0·455
15	Cupola, 1st sample	0·142	0·301	0·205	0·312	0·255	0·002	0·045	0·003	0·047	0·024
16	Cupola, 2nd sample	0·078	0·113	0·116	0·114	0·114	0·004	0·061	0·006	0·063	0·037

* Thus in No. 1 the Arsenic remaining in the Spongy Regulus constitutes 0·058 per cent. of the entire weight of the regulus; and that concentrated in the Bottoms constitutes 0·231 per cent. of the entire weight of the bottoms.

† Thus in No. 1 the Arsenic remaining in the Spongy Regulus, and constituting 0·058 per cent. of the weight of the regulus, is 0·075 per cent. of the weight of the Copper in the regulus; and the weight of the total Arsenic in the regulus and bottoms together is 0·088 per cent. of the weight of the total Copper in both.

Percentages of Bismuth, Lead, Sulphur, Iron, and Tin, in Copper Regulus and Copper Bottoms; and corresponding percentages† on Copper.*

Pb = LEAD. S = SULPHUR. Fe = IRON. Sn = TIN.

No. of Sample.	Description of Sample.	Bismuth: Percentage in Regulus.	Bismuth: Percentage in Bottoms.	Bismuth: Percentage on Copper: Regulus.	Bismuth: Percentage on Copper: Bottoms.	Bismuth: Percentage on Copper: Total.	Pb, S, Fe, Sn: Percentage in Regulus.	Pb, S, Fe, Sn: Percentage in Bottoms.	Pb, S, Fe, Sn: Percentage on Copper: Regulus.	Pb, S, Fe, Sn: Percentage on Copper: Bottoms.	Pb, S, Fe, Sn: Percentage on Copper: Total.
No.		Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
1	Reverberatory Furnace, 1st sample	0·160	0·280	0·207	0·286	0·210	Pb 0·578 S 17·294 Fe 0·304	Pb nil S 1·065 Fe 0·023	Pb 0·747 S 22·35 Fe 0·393	Pb nil S 1·089 Fe 0·023	Pb 0·685 S 20 6 Fe 0·362
2	Experiment with Bismuth	0·062	0·160	0·088	0·167	0·090					
3	Matte and Cupric Oxide	0·064	0·431	0·081	0·447	0·121					
4	Reverberatory Furnace, 2nd sample	0·012	0·063	0·016	0·064	0·024					
5	Experiment *b*										
6	Experiment *d*										
7	Matte with Arsenic and Nickel, 1st sample	0·024	0·090	0·036	0·120	0·054					
8	Experiment *g*						Sn 0·030	Sn 2·01	Sn 0·037	Sn 2·06	Sn 0·453
9	Experiment *e*										
10	Matte with Arsenic and Nickel, 2nd sample										
11	,, ,, ,, ,, ,, 3rd sample										
12	Matte										
13	Matte	0·031	0·087	0·052	0·090	0·066					
14	Experiment *c* with Lead and excess of Iron						Pb 1·561	Pb 16·32	Pb 2·25	Pb 21·28	Pb 8·90
15	Cupola, 1st sample	0·005	0·007	0 007	0·007	0·007					
16	Cupola, 2nd sample	0·009	0·011	0·013	0·011	0·012	S 20·593 Fe 9·083	S 0·820 Fe 1·531	S 29·89 Fe 13·19	S 0·84 Fe 1·57	S 14·26 Fe 6·94

* Thus in No. 1 the Bismuth remaining in the Spongy Regulus constitutes 0·160 per cent. of the entire weight of the regulus; and that concentrated in the Bottoms constitutes 0·280 per cent. of the entire weight of the bottoms.

† Thus in No. 8 the Tin remaining in the Spongy Regulus, and constituting 0·030 per cent. of the weight of the regulus, is 0·037 per cent. of the weight of the Copper in the regulus; and the weight of the total Tin in the regulus and bottoms together is 0·453 per cent. of the weight of the total Copper in both.

TABLE 5 (*continued from preceding page*).—*Summary of Results of Analyses.*

*Percentages * of Silver and Gold in Copper Regulus and Copper Bottoms; and corresponding percentages † on Copper.*

No. of Sample.	Description of Sample.	SILVER. Percentage in Regulus.	SILVER. Percentage in Bottoms.	SILVER. Percentage on Copper. Regulus.	SILVER. Percentage on Copper. Bottoms.	SILVER. Percentage on Copper. Total.	GOLD. Percentage in Regulus.	GOLD. Percentage in Bottoms.	GOLD. Percentage on Copper. Regulus.	GOLD. Percentage on Copper. Bottoms.	GOLD. Percentage on Copper. Total.
No.		Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
1	Reverberatory Furnace, 1st sample . .	0·0249	0·0660	0·0323	0·0674	0·035	0·00024	0·0024	0·00031	0·00245	0·00049
2	Experiment with Bismuth . . .										
3	Matte and Cupric Oxide	0·030	0·092	0·038	0·095	0·046	nil	0·0011	nil	0·00113	0·00016
4	Reverberatory Furnace, 2nd sample . .	0·019	0·061	0·025	0·062	0·031	nil	0·0019	nil	0·0019	0·0003
5	Experiment *b*	0·0251	0·0932	0·0343	0·0987	0·0454	nil	0·0103	nil	0·0109	0·0019
6	Experiment *d*	0·0207	0 0825	0·025	0·0825	0·0365	nil	0·0087	nil	0 0087	0·0016
7	Matte with Arsenic and Nickel, 1st sample	0·062	0·101	0·094	0·141	0·102					
8	Experiment *g*										
9	Experiment *e*										
10	Matte with Arsenic and Nickel, 2nd sample	0·050	0·093	0·096	0·125	0·104					
11	,, ,, ,, ,, ,, 3rd sample	0·051	0·110	0·084	0·144	0·101					
12	Matte	0·023	0·086	0·040	0·098	0·057	nil	trace			
13	Matte	0·030	0·092	0·051	0·096	0·066	nil	trace			
14	Experiment *c* with Lead and excess of Iron	0·009	0·0504	0·013	0·0748	0·031	0·00008	0·0022	0·00012	0·0029	0·0011
15	Cupola, 1st sample	0·0134	0·0121	0·0193	0·0437	0·0309	trace	0·00032	trace	0·00032	0·00016
16	Cupola, 2nd sample	0·0074	0·0226	0·011	0·023	0·017	nil	0·0013	nil	0·0013	0·00073

* Thus in No. 1 the Silver remaining in the Spongy Regulus constitutes 0·0249 per cent. of the entire weight of the regulus; and that concentrated in the Bottoms constitutes 0·066 per cent. of the entire weight of the bottoms.

† Thus in No. 1 the Silver remaining in the Spongy Regulus, and constituting 0·0249 per cent. of the weight of the regulus, is 0·0323 per cent. of the weight of the Copper in the regulus; and the weight of the total Silver in the regulus and bottoms together is 0·035 per cent. of the weight of the total Copper in both.

TABLE 5 (*concluded from page 261*).—*Additional Experiments.*

Experiment.	Products of Fusion.		Copper.		Antimony.		Pb = Lead. Bi = Bismuth.		Silver.		Gold.	
	Weight of Regulus.	Weight of Bottoms.	Percentage in Regulus.	Percentage in Bottoms.	Percentage in Regulus.	Percentage in Bottoms.	Percentage in Regulus.	Percentage in Bottoms.	Percentage in Regulus.	Percentage in Bottoms.	Percentage in Regulus.	Percentage in Bottoms.
	Grammes.	Grammes.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
a	93·25	18·0	72·71	96·03					0·0289	0·0940	trace	0·0095
b 1	124·5	20·5	72·07	93·21	0·0036	1·034			0·0237	0·0990	nil	0·0125
b 2	126·5	20·5	73·10	94·37	0·043	1·121			0·0251	0·0932	nil	0·0103
c 1	143·5	21·0	65·47	71·75	0·103	1·219	Pb 7·43	Pb 9·21	0·0360	0·1225	0·0010	0·0083
c 2	104·5	50·5	67·32	60·43	0·014	0·952	Pb 1·56	Pb 16·32	0·0090	0·0504	0·00008	0·0022
f	112·5	37·25	71·43	94·32			Bi 0·048	Bi 0·099				

TABLE 6.—*Concentration* of several foreign Metals in Copper Bottoms,*

when various percentages of total Copper are separated in that form. See Fig. 21, *Plate* 46.

Sample.	Description of Sample.	Copper in Bottoms.	Arsenic.	Antimony.	Bismuth.	Ni=Nickel. Sn=Tin. Pb=Lead.	Silver.	Gold.
No.		Per cent. (Percentage of total Copper.)	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
1	Reverberatory Furnace, 1st sample . .	8·2	21·5	21·0	11·1	Ni 8·2	15·8	41·5
2	Experiment with Bismuth	9·6			16·0			
3	Matte with Cupric Oxide	14·4			48·2		29·8	100·0
4	Reverberatory Furnace, 2nd sample . .	16·0	30·6	65·7	43·1		31·7	100·0
5	Experiment *b*	17·3		80·8			37·4	100·0
6	Experiment *d*	19·0					42·9	100·0
7	Matte with Arsenic and Nickel, 1st sample	19·3	77·7		46·4	Ni 47·9	26·7	
8	Experiment *g*	20·6				Sn 93·4		
9	Experiment *e*	25·2	60·2					
10	Matte with Arsenic and Nickel, 2nd sample	26·7	81·3				35·1	
11	,, ,, ,, ,, ,, 3rd sample	28·3	83·9				40·4	
12	Matte	29·3		87·1			50·6	100·0
13	Matte	34·7	66·4	88·4	47·8		49·8	100·0
14	Experiment *c* with Lead and excess of Iron	35·0		97·0		Pb 83·5	74·5	92·8
15	Cupola, 1st sample	47·5	58·0	93·7	47·6		67·2	100·0
16	Cupola, 2nd sample	54·5	54·5	92·6	50·3		71·5	100·0

* Thus in No. 8, when 20·6 per cent. of the total Copper is separated in Bottoms, there is concentrated in it 93·4 per cent. of the total Tin present in the original mixture; so that the remaining 6·6 per cent. of Tin is all that is left behind in the Spongy Regulus.

TABLE 7.—*Relative Impurity* of Copper remaining in Spongy Regulus, and of Copper before separation of Bottoms.* *See Fig. 22, Plate 47.*

Sample.	Description of Sample.	Copper in Bottoms. Percentage of total Copper.	Arsenic.	Antimony.	Bismuth.	Ni=Nickel. Sn=Tin. Pb=Lead.	Silver.	Gold.
No.		Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
1	Reverberatory Furnace, 1st sample . .	8·2	85·2	86·0	98·5	Ni 100·0	92·2	63·2
2	Experiment with Bismuth . . .	9·6			97·7			
3	Matte with Cupric Oxide . . .	14·4			67·0		82·6	
4	Reverberatory Furnace, 2nd sample . .	16·0	82·1	40·7	66·6		80·6	
5	Experiment *b*	17·3		23·2			75·3	
6	Experiment *d*	19·0					68·4	
7	Matte with Arsenic and Nickel, 1st sample	19·3	28·3		66·6	Ni 64·6	92·1	
8	Experiment *g*	20·6				Sn 8·2		
9	Experiment *e*	25·2	45·5					
10	Matte with Arsenic and Nickel, 2nd sample	26·7	27·2				88·4	
11	,, ,, ,, ,, ,, 3rd sample	28·3	22·5				83·2	
12	Matte	29·3		18·0			70·1	
13	Matte	34·7	50·3	17·6	78·8		77·1	
14	Experiment *c* with Lead and excess of Iron	35·0		4·6		Pb 25·3	42·0	11·0
15	Cupola, 1st sample	47·5	80·4	12·5	100·0		62·4	
16	Cupola, 2nd sample	54·5	100·0	16·2	108·3		64·7	

* Thus in No. 8, if before fusion the total Tin is 0·453 per cent. of the total Copper (Table 5), and if the Tin left in the Spongy Regulus is 0·037 per cent. of the Copper remaining in the regulus, the latter percentage is 8·2 per cent. of the former, as given in this Table 7. That is, as regards tin, the *impurity* of the copper remaining in the regulus is 8·2 per cent. of the *impurity* of the copper before fusion; or the *purity* of the copper remaining in the regulus is more than twelve times as great in respect of tin as the *purity* of the copper before fusion.

It is hence clearly evident that in the process for making "best selected" copper the proportion of copper separated as bottoms should not exceed 20 per cent. of the total copper in the furnace charge, a larger proportion having the effect not only of diminishing the yield of "best selected" copper from the spongy regulus, but also of impairing its purity.

For Discussion see page 280.

APPENDIX 2 TO THIRD REPORT TO THE ALLOYS RESEARCH COMMITTEE.

THE PYROMETRIC EXAMINATION OF THE ALLOYS OF COPPER AND TIN.

By Mr. ALFRED STANSFIELD, Associate of the Royal School of Mines

The experiments here recorded were made in the research laboratory of the Mint, with a view to obtain, by means of Professor Roberts-Austen's autographic recording pyrometer,* curves which should represent the cooling of a series of alloys of Copper and Tin. As in other photographic curves which have been published in these Reports, the ordinates give the temperature of the alloy, which is cooling in a crucible, and the abscissæ represent the time occupied in its cooling. A selection from the numerous curves taken will show the nature of the results obtained.

Autographic Cooling Curves.—In Fig. 10, Plate 41, it will be noticed that at certain points the curves become less steep or even horizontal for a short distance, and then resume their original directions. This change is caused by the evolution of the latent heat of fusion in the alloy; and is not due, as it sometimes is in the cooling of metallic masses, to molecular changes occurring in the solid.† The alloys were placed in a thick crucible, made by luting a small clay crucible inside a larger one of graphite, as shown half size in Fig. 13, Plate 44. The lid fitted loosely within the outer crucible; and a clay tube, having its lower end closed, passed through a hole in the lid. The wires forming the thermo-couple passed down the tube, being insulated by slips of mica, and were fused together at the bottom. The two metals to form the alloy were melted together, and were covered with powdered electric-light carbon, which proved very effective in preventing loss by oxidation. When the alloy was thoroughly liquid, the crucible was removed from the

* See First and Second Reports: Proceedings 1891, page 551; and 1893, page 132. † See ibid: 1891, page 543; and 1893, page 102.

fire; and the lid, tube, and thermo-couple, all of which had been previously heated, were placed in position. The recording apparatus was then started, and the curve of cooling traced autographically.

These photographic curves were calibrated by reference to similar curves which showed the freezing points of gold, aluminium, lead, and tin: the respective melting points being taken as 1045°, 625°, 326°, and 227° C.; or 1913°, 1157°, 618°, and 441° Fahr. The boiling points of water 100° C. or 212° F., and of sulphur 448° C. or 838° F., were also used in calibration. In Fig. 10, Plate 41, the cooling curves for the series of alloys have been plotted with time and temperature as co-ordinates; and they are so arranged that the point at which each curve intersects the horizontal "composition" line PP marks the percentage of copper in the alloy represented by the curve.

Freezing Points.—Beginning at the copper end of the series, it will be seen that pure copper has a single fairly sharp freezing point; the temperature of the metal falls only slightly during solidification, Fig. 10, Plate 41. As successive additions of tin are made, the freezing point of the alloy is lowered; and the part of the curve which represents the freezing of the mass becomes steeper, and more rounded at the lower end.

In the cooling of the alloy containing 90 per cent. of copper, it appears that, while the alloy as a whole freezes at 1000° C. or 1830° F., a small portion remains liquid until 770° C. or 1420° F. is reached. Alloys containing about 80 per cent. of copper solidify in three distinct stages; and those containing from 50 to 25 per cent. of copper have no fewer than four separate freezing points.

This method of arranging the curves brings into prominence several points of interest. It will be seen that each of the alloys, excluding those at either end of the series, has at least two separate freezing points; most of them have either three or four. Lines marked *aa*, *bb*, *cd*, *ee*, and *ff* respectively, are drawn through these freezing points. Three of these connecting lines, *bb*, *ee*, and *ff*, are approximately horizontal; one of the others *cd* may be regarded as two horizontal lines, *cc* and *dd*, together with a connecting portion;

and the other line *aa* is curved. This curved line *aa* connects the highest freezing points of each alloy: the points, that is, at which the most infusible portion of the liquid alloy solidifies. The other lines being horizontal show that in most of the alloys, although the proportions of tin and copper, of which the liquid mass is composed, may vary widely, there are always particular groupings of tin and copper which remain liquid for a considerable time, and then become solid at definite temperatures. It will be evident that there are five sets of such groups, marked respectively by the lines *bb*, *cc*, *dd*, *ee*, and *ff*.

The group which remains liquid longest in the alloys containing more than 50 per cent. of tin, and the freezing of which is indicated by the line *ff*, Fig. 10, Plate 41, probably corresponds with the eutectic alloys (that is, the most fusible alloy of each series) discovered by Dr. Guthrie * in other series of metallic alloys. It should be remembered that long ago Rudberg † showed that every member of the lead-tin series of alloys, with one exception, had two freezing points; the lower of which was always at 187° C. or 369° F. In the copper-tin series the melting points of the several groups are widely divergent; and this may account for the fact that no alloy has been found in which the freezing points coalesce in one point. In the alloy containing 73 per cent. of copper, two of the freezing points coalesce, which were quite separate in the alloy containing 77 per cent. of copper. A similar coalescence of two points takes place in the alloy containing 20 per cent. of copper, and also in the alloy containing 10 per cent. of copper. Riche ‡ supposed that the alloys having the atomic proportions indicated by the formulae $Sn\,Cu_3$ and $Sn\,Cu_4$ had only single freezing points; but in this he appears to have been mistaken, and the solidification of all these groups could hardly have been detected without the delicate method of investigation described in these Reports.

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* Philosophical Magazine, vol. xvii, 1884, page 462. See also Proceedings 1891, page 556.

† Poggendorf's Annalen, vol. xviii, page 240, and vol. xix, page 125. Annales de Chimie et de Physique, vol. xlviii, 1891, page 353.

‡ Annales de Chimie et de Physique, vol. xxx, 1873, page 417.

The lower freezing points, which fall on the horizontal lines *ee* and *ff*, Fig. 10, Plate 41, appear to represent the crystallisation of definite compounds, rather than the freezing of a mother liquor after other compounds have fallen out of solution ; and it seems likely that these definite compounds were formed while the alloy was molten, and not merely during solidification. The relative osmotic pressure exerted by the liquid copper and tin—that is, the mutually interpenetrating force of their molecules—and the degrees of stability of the different compounds, will determine what quantity of each of these groups is formed. The respective groups of tin and copper atoms which fall out of solution are not merely *rejected* by the portions of the alloy which freeze first. The constitution of a solidified alloy of copper and tin may therefore depend on the temperature to which the molten alloy has been raised, and on the time during which it has been in the molten state. An alloy of copper and tin, which had been maintained molten for nearly a week, showed on analysis metallic crystals of a copper-tin compound, which were insoluble in nitric acid: although all the known alloys of copper and tin are readily soluble in nitric acid. Similar crystals, but in much smaller quantities, were found in alloys which had not been so long melted. This compound of difficult solubility appears to form slowly, like certain other chemical compounds.

Other Physical Properties.—In Fig. 11, Plate 42, the foregoing lines *aa* to *ff*, which connect the freezing points of the several alloys, have been plotted with temperature and percentage of copper as co-ordinates: thus showing at a glance the number and respective temperatures of the freezing points of an alloy which contains any given percentage of copper. Curves representing various other physical properties of the copper-tin series are plotted for comparison. Curve EMF shows the electromotive force, as determined by Professor A. P. Laurie,* of a voltaic cell containing stannous chloride, which has for one pole the alloy to be tested, and for the other a copper wire coated with cuprous chloride. Curve EC represents the electrical

* Journal of the Chemical Society, 1888, page 104.

conductivity of the members of the copper-tin series, as determined by Lodge.* I is the induction-balance curve of Professor Roberts-Austen.† H is the conductivity for heat, according to Calvert and Johnson.‡

The sudden fall which is produced in the electrical conductivity of copper by the first addition of tin, Fig. 11, Plate 42, has been given as evidence of molecular change. The sharpness of the freezing point of copper is also destroyed by slight additions of tin; and surfusion—that is, the property of cooling below the freezing point before actually becoming solid—which appears to be a test of the purity of copper, has been observed only in a sample of particularly pure electrotype copper. Tin, on the other hand, shows surfusion, Fig. 10, Plate 41, even when alloyed with 5 per cent. of copper.

The first appearance of a second freezing point occurs in the alloy which contains 90 per cent. of copper. The first great break in the electrical conductivity curve also occurs in an alloy which contains 91 per cent. of copper, Fig. 11, Plate 42. The alloy $Sn\,Cu_4$ freezes almost entirely at 750° C. or 1380° F.; and the group of copper and tin, which in the 90 per cent. copper alloy freezes at 760° C. or 1400° F., will probably contain nearly the same percentage of copper as $Sn\,Cu_4$. Now $Sn\,Cu_4$ has the worst conductivity of the whole series: so that the low conductivity of the alloys which contain from 70 to 90 per cent. of copper is evidently due to the presence in these alloys of the particular group of copper and tin which freezes at 760° C. or 1400° F.

The increase of electrical conductivity between $SnCu_4$ and $SnCu_3$, Fig. 11, Plate 42, and the more marked rise in the induction-balance curve I, as well as in that of heat conductivity H, have probably some connection with the rise and increased importance of the line *cd*, and may depend on the change of the alloy from the vitreous to the crystalline condition; while the still more sudden rise in the electromotive-force curve EMF—between $Sn\,Cu_3$ which

* Philosophical Magazine [5], vol. viii, 1879, page 554.

† *Ibid.*, page 551.

‡ Thurston's Report on the Alloys of Copper and Tin, 1879, Plate xiv.

contains 61·6 per cent. of copper, and the alloy containing 60 per cent. of copper—appears to be due to the presence of one or both of the groups of copper and tin, whose freezing points lie on the lines *ee* and *ff*. The observed change in electromotive force would be produced by smaller quantities of these groups than would be required to produce a visible freezing point in a cooling curve. In general it may be stated that the changes in the physical properties of the copper-tin series, which take place between the alloy containing 60 per cent. and that containing 70 per cent. of copper, are due to the re-grouping which occurs of the constituent metals. In alloys containing more than 70 per cent. of copper, the tin and copper are combined in groups whose freezing points lie on the lines *bb* and *cc*; while in alloys containing less than 60 per cent. of copper, the metals form the totally different groups of tin and copper atoms, whose freezing points lie on the lines *dd*, *ee*, and *ff*.

Tensile Strength and Elongation.—In Fig. 12, Plate 43, are plotted curves showing the ultimate tensile strength and elongation of the alloys of the copper-tin series, together with the foregoing lines *aa* to *ff* joining the freezing points of the several alloys; these mechanical tests are taken from Thurston's report * on the copper-tin series. The results of mechanical tests are in themselves complicated: tensile elongation, for instance, appears to require a certain degree of hardness; and the increase of extensibility which follows the addition of a small quantity of tin to copper, or of copper to tin, may be the result of an increase of hardness. On the other hand the sudden decrease of extensibility which follows further additions of copper to tin, or of tin to copper, and the peculiar hollow which in the curve of tensile strength characterises the alloys containing about 90 per cent. of copper, occur almost simultaneously with the appearance of double freezing points. An alloy composed of two or more groups of metals, which have different freezing points and are mechanically mixed with each other, is less likely to be ductile than one in which the metals are homogeneously united; and the groups

* Report on the Alloys of Copper and Tin, 1879, page 456, and Plate ii.

of tin and copper atoms which fall out of solution are probably of a brittle nature. The fractures of the specimens may be noticed in connection with their mechanical properties. The great decrease in the strength of the copper-tin alloys, which takes place when the amount of tin is increased beyond about 20 per cent., is connected with a change in their crystalline character, which ceases to be finely granular, and becomes vitreous. The group or compound of tin and copper which produces this vitreous character has its freezing point at 760° C. or 1400° F. on the line *bb*, and forms nearly the whole of the alloy $SnCu_4$; so that this group would appear to contain about 70 per cent. of copper. It is probably this group which produces the remarkably sharp initial freezing point of the alloy containing 65 per cent. of copper; and the surfusion and the sharpness of this freezing point are quite exceptional in alloys of the copper-tin series. The crystalline fracture of the alloy $SnCu_3$ is quite different from the vitreous fracture of $SnCu_4$; and this difference is evidently connected with the change in the group of tin and copper which forms the more fusible constituent of these alloys. In the alloy $SnCu_4$ the more fusible constituent freezes at 570° C. or 1060° F., and is present only in small quantity; while in $SnCu_3$ it freezes at 650° C. or 1200° F., and forms about one-third of the whole mass. The group which freezes first in $SnCu_4$ is also modified in $SnCu_3$ by the presence of an excess of tin. Among all the alloys of the series which have more than 10 per cent. of each metal, $SnCu_3$ is peculiar in having its two freezing points nearly united: thus accounting for the slight evidence of liquation—that is, separation of its more fusible constituents—which can be detected in it. $SnCu_4$, which also shows scarcely any liquation, has its freezing points more widely separated; but in this alloy the more fusible constituent is present only in small quantity.

Colour.—The colour of copper is rapidly destroyed by the addition of tin; only those alloys which contain more than 70 per cent. of copper have any of the copper colour left. Now all these alloys which retain the copper colour have an initial freezing point above the line *bb*, Fig. 10, Plate 41. The constituent of each of these

alloys which produces the initial freezing point is copper dissolved in tin; the copper, not having combined chemically with the tin, but being in a state of solution in the liquid tin, retains a certain amount of its original colour. The least fusible constituent of each of the alloys that contain from 20 to 70 per cent. of copper may be regarded as being the group which in other members of the series freezes at 760° C. or 1400° F.; and in these alloys this group is diluted with a varying amount of tin. The blue tinge of colour, which is seen in the alloys containing from 52 to 62 per cent. of copper, appears to be due to the presence of the group whose freezing point lies on the line *dd*, Fig. 10, Plate 41. In alloys containing more tin, this group is less developed and no blue colour is visible. The alloys which contain from 20 to 40 per cent. of copper are composed of white platy semi-flexible crystals, and show segregation of a yellow compound. Still further additions of tin produce grey alloys containing small crystals, which disappear as pure tin is approached.

In this way, by considering the various physical properties and the crystalline form and colour of the members of the copper-tin series, in connection with the cooling curves of these alloys, it is possible to obtain a general knowledge of the nature of the several groups of tin and copper, of which each alloy is composed. In order to obtain further information about these groups, it would be necessary to separate them: either by liquation, in the same way that Dr. Guthrie separated his eutectic alloys, straining off the more fusible constituent from a mass in which the less fusible constituents had crystallised out; or else, by separating the groups in the solidified alloy, by chemical or electro-chemical methods. As an example of the latter mode of procedure may be noted Professor Laurie's experiments on the electromotive force of the copper-tin alloys. He found that, by using an alloy containing rather less than 60 per cent. of copper as one pole of a voltaic cell which contained stannous chloride, the other pole being of copper coated with cuprous chloride, tin was removed from the alloy until its composition approximated to 60 per cent. of copper. In this case it would appear that what was removed was not *pure* tin, but one or both of

the groups, containing a large percentage of tin, whose freezing points are on the lines *ee* and *ff*.

Practical Applications.—The present research is of considerable interest in regard to the industrial use of the various copper-tin alloys, such as gun-metal, bell-metal, speculum metal, and bronzes in general. It has been stated in works on the alloys of copper and tin that the most fusible constituent of gun-metal melts at 500° C. or 930° F.; and the line *cc* in Fig. 10, Plate 41, is found to lie at 500° C. or 930° F., thus agreeing with previous observations. By simply taking a cooling curve from a small sample of any alloy, a manufacturer will be able to obtain much useful information about it. He can see at a glance its mode of aggregation, on which, as has been shown, its physical properties so largely depend. He can ascertain its degree of fusibility, which affects its value as a material for casting. He will be able to measure the temperature at which its most fusible constituent freezes, which not only indicates the mechanical properties of the alloy when cold, but also practically determines to what temperature it may be heated without serious loss of strength.

Annealing.—The temperatures at which the several constituents freeze will indicate the method which must be employed to anneal the alloy. Alloys like the bronzes, which have a fusible constituent freezing at a temperature considerably below that at which the main part of the alloy solidifies, are *annealed* (not hardened) by heating to a red heat and *chilling*. The more fusible part of the alloy is thus melted, and made to solidify quickly, causing fineness of grain. The influence however of rapid or slow cooling varies in the several members of the series. In taking the cooling curves in the present experiments, the alloys were cooled to the freezing point of tin in about forty-five minutes, the weight of each sample being four ounces. When cooled in this manner, the alloy $SnCu_3$ solidified in large shining crystals; when however it is cast in small iron ingot-moulds, it becomes minutely crystalline, and has a decidedly blue colour. Speculum metal $SnCu_4$ freezes almost

entirely at its higher melting point, and is nearly unaffected by slow or rapid cooling. Consequently in practice, while gongs and most articles of bronze are *tempered* by being heated to redness and cooled quickly, speculum mirrors for telescopes are cooled extremely slowly in order to anneal them.

Tenacity.—Important information as to the probable behaviour of alloys at high temperatures is also afforded; for although the temperature at which marked decrease in strength occurs is below the lowest freezing point of the alloy, it nevertheless appears to have some connection with it. Thus copper containing 0·1 per cent. of bismuth, which would have a freezing point at about 268° C. or 514° F., has at 160° C. or 320° F. only one-third of the tenacity which it possessed at 15° C. or 59° F.; while gun-metal, which has its lowest freezing point at 500° C. or 930° F., does not show any marked decrease in strength until 300° C. or 570° F. is reached. Pure copper or arsenical copper, in which the freezing point is high, does not show any considerable loss of strength at these temperatures.

Summary.—(1) No alloy of copper and tin which contains more than 5 or 10 per cent. of either metal solidifies as a whole; in each member of the copper-tin series there are at least two constituents, or groups of tin and copper atoms, which freeze at different temperatures. It is unlikely therefore that any alloy of tin and copper, which has been produced by melting in the ordinary way, is itself a simple chemical compound, though it may contain definite compounds.

(2) There is evidence of the existence, in alloys of tin and copper, of four or five distinct groups of tin and copper atoms, three of which appear to be fairly definite in composition. These may be either chemical compounds, which are capable of dissolving to a certain extent in excess of tin or copper; or they may be particular cases of the solution of copper in tin. The groups are probably formed by the affinity of copper and tin when in the molten state; and as they never occur singly, they would appear to be unstable, no one group of tin and copper being produced to the exclusion of all the others.

(3) The initial freezing point appears to represent, in the alloys containing more than 70 per cent. of copper, free copper containing dissolved tin; while in the alloys containing less than 70 per cent. of copper, the initial freezing point seems to represent an excess of tin, dissolved, not in free copper, but in one of these special groups of tin and copper atoms.

(4) A comparison of the series of cooling curves with the physical and mechanical properties of the alloys, and with the appearances of their fractured surfaces, confirms the belief in the existence of these special groups; and indicates that the peculiar and sometimes sudden changes in the physical properties of alloys may often be explained by the appearance and disappearance of these groups.

For Discussion see page 280.

Discussion.

Professor Roberts-Austen said that in the preparation of this third Report he must confess to having asked himself wherein lay its particular utility for the Members of this Institution as an eminently practical body. One answer already given in the report itself was that the work started by the Alloys Research Committee had been fruitful in connection with anti-friction alloys, a subject of considerable importance to engineers, on which he hoped Professor Goodman would himself have something to say. During the progress of the work also some remarkable facts had been observed connected with the tenacity of metals. The experiments that had been made during the two years which had elapsed since the previous report were largely in excess of anything that could be included in the present report; and it was to the immediate future that he looked for useful applications, rather than to the particular facts now placed before the Institution. The special research bearing upon the useful properties of the alloys now dealt with was the investigation of their freezing points by means of the autographic cooling curves shown in the diagrams exhibited. Here the vertical ordinates represented temperature, and the horizontal abscissæ time. As the liquid mass cooled down, the course of the cooling curve ran obliquely downwards, until the metal began to freeze. There was then a halt in the downward course of the curve, which turned into a horizontal direction, and continued as a horizontal line while the metal was freezing. When the mass was frozen solid, the cooling curve resumed an oblique downward course as before. It was rarely however that an alloy solidified as a whole; as described in the report, it seldom settled down or became solid all at once. It might be that certain subsidiary groups of atoms froze separately before the mass solidified, while yet others froze at a lower temperature than the main portion of the mass. Hence it was better in dealing with these cooling curves to speak of the freezing point, instead of the melting point, because the latter was not quite the same as the point at which the mass became solid in cooling. [An experiment was here made to show how the curve for the freezing of a small

mass of gold was obtained by means of a thermo-junction and a galvanometer with a mirror.] Of the two thermo-junction wires attached to the galvanometer one consisted of platinum, and the other of platinum with 10 per cent. of rhodium; their other ends were simply twisted together to form the junction, and a single twist was electrically as good as a number, though it was better for the sake of security to have several. On heating the junction a current of electricity was generated, and the electromotive force of this current was a measure of the temperature to which the thermo-junction had been raised. Consequently in the experiment just made, when the thermo-junction was plunged into the molten gold, the deflection of the galvanometer mirror was a measure of the temperature of the metal. The curve obtained in the experiment just made exhibited the phenomenon of surfusion, well known to occur with ice; it was seen by the dip in the curve that the molten gold had actually passed down a little below its true solidifying point without becoming solid; then its temperature gradually rose again to its true solidifying point, at which the curve became approximately a horizontal line, and remained so while the mass of the metal was becoming solid; then it turned off downwards as the solidified mass cooled. In this experiment particular interest attached to the dip in the curve just preceding the horizontal portion, inasmuch as the shape of this dip, corresponding with the surfusion of the mass, afforded a delicate indication of the purity of the metal or alloy under investigation. In some metals, tin and bismuth for example, the surfusion was marked by a dip of V shape, having a sharp angle at the bottom, and turning sharply horizontal on rising to the true solidifying temperature; and again on completion of the freezing the horizontal line turned sharply downwards. When the angles of these bends were all sharp, the material was particularly pure; and if the gold here experimented upon had been pure, the line traced would have had, not the well rounded curve of the dip here shown, but a dip with sharp corners. The rounding of the dip showed what had happened: the platinum wires had not been protected from the gold, the whole mass of which was hardly larger than a pea;

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and the experiment having been rehearsed several times in order to make sure of its success, the result had been that the gold had become contaminated with a little platinum; and this was the impurity indicated by the roundings of the curve. Had it been possible in the experiment just made to trace the entire continuation of the cooling curve below the point of solidification, and had the gold contained a small amount of bismuth, which in the present instance it did not, the second subsidiary halt would have been caught at the lower temperature of about 227° C. or 441° F. which was seen in the curve shown in Fig. 7, Plate 39. If the gold here experimented upon had revealed this subsidiary halt, it might have been broken with a slight blow. In all the alloys examined in this research the existence of this low subsidiary halt in the cooling curve indicated weakness: though the weakness might to a certain extent be overcome by mechanical work put upon the metal.

There was an alloy of tungsten and copper called by electricians platinoid, although it did not contain platinum, which had a melting point at 1,200° C. or 2,190° F. and high tenacity. Plotting this on a diagram whose vertical ordinates represented temperature, and its horizontal abscissæ tenacity, and plotting also pewter with a low melting point of 200° C. or 390° F. and a low tenacity, and joining these two points by an oblique line, it was then found that on similarly plotting the melting point and tenacity of any other alloy—it might be gun-metal, bell-metal, speculum metal, bronze, or brass—they would in general fall approximately on that oblique line. There were few alloys yet examined which did not; these were under investigation. It was astonishing in how many cases the determination of the melting point gave a marvellously close approximation to the strength of the material, provided always that the material was in its strongest form as the result of mechanical work put upon it: cast-metal did not comply with this proviso. What the full significance was of this discovery he did not yet know; but it seemed to show that it did not matter what was put into the alloys, provided their melting points were kept high.

There was one remark to make rather as a warning in regard to the electrical pyrometer: namely that the thermo-junction was only

an indirect means of measuring high temperatures. Many eminent iron-masters throughout the country were now using it for measuring the temperature of hot blast and for other purposes; but in all cases the value to be attached to any given deflection of the galvanometer or any given deviation of the ray of light had to be determined by separate calibration. The standard of reference taken by everyone who was using the particular form here shown of the pyrometer was the melting point of gold, namely 1,045° C. or 1,913° F. This had been determined with the utmost care by Deville many years ago. The melting points had also been most carefully determined of silver, aluminium, zinc, cadmium, and other metals. But it had recently been concluded that these temperatures, which were originally believed to be a little too high, were in reality a little too low; it might be that the melting point of gold was 17° C. or 31° F. higher than just quoted. If he had corrected the whole of the present report in accordance with the latest investigations, then all the temperatures would have been a little higher than they were here given; but they had not been so corrected, because for temperatures above 700° C. or 1,300° F. the evidence that they were somewhat higher than he had here given them rested on mathematical deductions rather than on direct experiment. Therefore in the absence of direct experiment, which was exceedingly difficult to make, he thought it would be wise, and M. Le Chatelier agreed with him, to leave the temperatures for the present where they were, even though somewhat later they might have to be increased a little.

Mr. Thomas Wrightson, M.P., said, with regard to the particular work with which his name had been associated in this report, the series of experiments, which through the kindness of Professor Roberts-Austen he had been enabled to carry out at the Mint, had been simply a continuation of a series of experiments which he had presented in 1879–80 to the Iron and Steel Institute (Journal 1879, pages 438–46; and 1880, part 1, pages 19–24). His object had then been to investigate the phenomenon of the setting of cast-iron in cooling from its liquid state. Cast-iron was particularly suitable

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for the purposes for which it was used, owing to the fact that it expanded somewhat in setting. About twenty years ago there was a good deal of correspondence in the engineering papers as to the reason why solid cast-iron should apparently float in liquid cast-iron. On throwing a piece of cast-iron into the molten liquid iron, it had been noticed that it apparently floated at once. If however it was carefully watched, it would be found that the solid piece really did not float directly, but sank in the first instance and then rose to the surface. From careful experiments made with balls of cast-iron, of which the specific gravities had been carefully taken so as to be certain there were no cavities in the iron, he had found in every case that the ball if lowered slowly into the molten iron sank at first, and after a few seconds showed itself at the surface. This was obviously due to the fact that the heat penetrating the cold ball expanded it, so that it displaced more liquid. The same thing he believed had been observed by others; but the particular fact which he had watched with interest was one which, so far as he was aware, had not been noticed specially before: namely that after the ball appeared at the surface of the liquid iron it continued rising to a considerable extent above the surface, and in many of the experiments it seemed to rise till something like one-sixteenth of its volume was above the surface. This clearly showed that a much larger expansion was taking place than had perhaps been suspected before. He thought it worth investigating what the amount of this expansion really was, and the rate at which it took place; and he designed an instrument in order to measure it. The ball to be submerged in the liquid iron was hung upon a spiral spring, such as was used in an ordinary spring-balance; the instrument was supported on a frame hung from a tripod above the ladle of iron, and the ball being lowered several inches below the surface of the molten iron, the index of the spring was thereby brought back closely to zero. The expansion of the ball as the heat passed into it was then registered by the compression of the spring, because as the ball expanded and displaced more liquid its flotation became greater; and its rising to the surface being opposed only by the resistance of the spring, the increase of volume was exactly

measured by the amount of compression of the spring; with a scale of ounces placed alongside, the upward motion of the ball and the exact number of ounces it was displacing in the course of heating could be read off. The instrument was evidently of the most simple kind, with hardly any mechanism intervening between the effect that was being examined and the register of that effect; thus if a ball weighing 100 ounces was plunged below the surface of the liquid metal, and the spring became compressed through an amount equivalent to one ounce, it was known at once that the ball had expanded one per cent. of its volume. By attaching a drum with a sheet of paper wound upon it and driven by clockwork, diagrams were obtained of the general form shown in Fig. 15, Plate 44, in which the horizontal element represented time and the vertical element expansion; the position of the base or datum line represented the volume of the ball when it was of the same specific gravity as the molten iron. When the ball was first put into the liquid metal, it was of a higher specific gravity. Then the expansion began, and in a few seconds the ball had expanded to the same density as the liquid metal; and at that moment, in the case of a free ball, its top would be just appearing at the surface. As the ball gradually rose higher and higher in temperature, the curve produced by the instrument continued rising, until at length the rise became so slow that the line was almost horizontal, and the volume of the ball did not seem any longer to increase. At the further end of this horizontal portion the line suddenly descended, indicating that the ball had rapidly melted away and joined the molten metal in the ladle. In the series of diagrams which had been taken in this way the amount of expansion shown was about 1 per cent. from the outset up to the datum line, and about 6 per cent. above the datum to the highest part of the curve, where the ball was in what would be called a plastic condition; the total expansion was therefore about 7 per cent. The first 1 per cent. of expansion at starting really corresponded with the 1 per cent. always allowed in the linear dimensions in making a pattern for an iron casting, in order to allow for the contraction of the casting in cooling.

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The same curve traced backwards ought also to represent the expansion of cast-iron in solidifying from the liquid state. This remarkable phenomenon of the considerable expansion of cast-iron in setting had brought to his mind the analogy of water when it was becoming converted into ice. It had long been known that water expanded 9·3 per cent. of its volume in solidifying into ice. According to these experiments the expansion of cast-iron was only 6 per cent. from the liquid to the plastic condition, or 7 per cent. from the solid to the plastic condition; but it seemed to be such an approximation to what was found to take place in water that it had occurred to him to suggest that the regelation of ice—which had been investigated by Helmholtz, Tyndall, Lord Kelvin, and others, and by them attributed to this property of water—might in all probability be the same order of phenomenon as the welding of wrought-iron or steel. At the time of making the experiments with cast-iron he had no means of testing the expansion of wrought-iron from the solid to the liquid state. He had therefore tried white iron, but found that, although he did get diagrams, yet the viscid nature of white iron rendered them not altogether satisfactory. No doubt the diagrams obtained clearly proved that the expansion of white iron was even greater than that of ordinary grey cast-iron; still the viscid character of the liquid white iron really prevented anything like such clear diagrams being obtained as those from grey iron. As white iron was so much nearer the condition of wrought-iron than grey iron was, it became evident there was not much hope of experimenting with wrought-iron in the same way that had been done with grey cast-iron, apart altogether from the consideration of the much greater heat required to melt it and the much greater difficulty of manipulation. The suggestion that the theory of the welding of iron might be similar to that of the regelation of ice unfortunately could not then lead much further, firstly because cast-iron did not weld, and secondly because without special experiment it could be only an assumption that wrought-iron did expand in cooling and contract in heating, like water and cast-iron. When Professor Roberts-Austen's admirable recording pyrometer made its appearance,

it occurred to himself that by the means thus furnished the subject might be approached through another avenue altogether. It had been shown theoretically by the late Professor James Thomson many years ago* that the effect of impact or pressure upon a substance which expanded in cooling and contracted in heating must necessarily be not to heat it but to cool it; and conversely that any substance which was cooled by pressure or impact must necessarily be a substance which expanded in cooling and contracted in heating. This had been experimentally confirmed by his brother Sir William Thomson, now Lord Kelvin, in his well-known experiment on the compression of melting ice, described in the Transactions of the Royal Society 1850. If then by experiment it could be shown that wrought-iron when in the welding condition suffered a fall of temperature on being subjected to pressure or impact, it would on Professor James Thomson's theory be a complete proof that wrought-iron followed the same law as water and cast-iron. On talking the matter over with Professor Roberts-Austen, the latter had most kindly offered facilities for making experiments at the Mint, and had not only assisted in all the important experiments and watched them himself, but had also allowed Mr. Stansfield and Mr. Reginald Roberts to assist in carrying them out; in fact they never could have been carried out, had it not been for the great aid he had received at the Mint. After many endeavours to weld in an ordinary fire and to apply the thermo-junction at the place where the weld was being made, it was found impracticable to get any trustworthy result in that way. At last the plan was hit upon of heating the iron by an electric current, which would prevent any mixture of dirt from the coal, and would do away with many other difficulties; and a complete apparatus, by which the experiment could be thoroughly tried, had been placed at his disposal by the Electric Welding Company. The mode of applying the thermo-junction was shown in Fig. 14, Plate 44. The two ends of the bar to be welded were brought

* Transactions of the Royal Society of Edinburgh 1849, vol. xvi, pages 575–80; Proceedings of the Royal Society 1859, vol. x, pages 152–60; British Association Report 1859, pages 23–6.

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together inside a porcelain tube, which was necessary in order to insulate the bar, as it was to be welded by means of an electric current. Through the pipe-stems, which were also insulators, were passed the wires of the thermo-junction, and these were thence carried round to the recording apparatus. There was a division in the steel die surrounding the porcelain tube, through which it could be seen when the iron came to the welding heat; then the electric current was turned off, and while the end pressure was being applied to weld the bar the photographic cooling curve was traced by the recording pyrometer. A series of experiments were made with the same bar, and in Plate 45 were shown five of the curves obtained. When the bar was pressed for the first time, Fig. 16, it was found that the curve did not show a fall but a rise of temperature from the point P at which the pressure was applied; and it had been pointed out by Mr. Stansfield that in all probability this might arise from the fact that the interstices of the porcelain envelope had not been filled, and that so long as they were not filled there would be a development of heat by pressing the plastic metal into them. At the moment of applying the pressure the temperature was about 1,350° C. or 2,460° F.; and after the first jump up in the curve the line gradually fell. In Fig. 17, when the pressure was put on, there was also a rise, showing generation of heat by displacement of material; and then the curve rapidly fell away, the fall being due to the current having been turned off and the temperature lowered in consequence. In Fig. 18 there occurred the first fall produced by the welding pressure. By the time this experiment was made, all the interstices had become fairly well filled up; and now for the first time was found what was looked for, namely a sudden fall in the temperature immediately on the application of the welding pressure. In Fig. 19 no doubt every interstice was entirely filled, for when the pressure was put on there was a marked fall of about 57° C. or 103° F. In the last experiment, Fig. 20, a similar fall was seen again, although not so marked as in Fig. 19, presumably on account of the bar having in this instance been heated only to 1,300° C. or 2,370° F. at the moment of the pressure being applied. Some time elapsed between

each of these five experiments, although made on the same bar. It was not attempted to make a weld, but merely to compress the bar when in a welding condition. The complete account of the experiments had recently been communicated to the Royal Society, and would be published in their Transactions.

Professor John Goodman said that, in investigating during the past two years the subject of anti-friction alloys, he had met with some curious occurrences. Some of the alloys, which were supposed from analysis to be precisely the same, being of the kind known as Babbitt's metal, gave different frictional results, the difference amounting in one instance to almost 100 per cent. The alloys were analysed only for lead, antimony, and tin; and the analyses showed that the percentages of these metals were approximately the same in all; at any rate there was nothing which would lead to the belief that it was a difference in these percentages which produced the difference in the friction. On further analysing the alloys however with closer accuracy, they were found to contain some minute impurities; and on taking careful note of these he had at last found distinctly that if an impurity added to the alloys were a metal of smaller atomic volume than the main body of the alloy—of which the atomic volume was roughly about 17—the friction would be largely increased, the actual increase depending upon the atomic volume of the added impurity. With aluminium, for example, having an atomic volume of 10·6, the addition of a tenth of one per cent. would produce from 20 to 30 per cent. more friction. The experiments had been repeated over and over again with very small quantities of lubrication and also absolutely dry, in order that there should be no question of lubrication affecting the results. Then on the other hand, if the impurity added were a metal of larger atomic volume than the main body of the alloy—such as bismuth having an atomic volume of 21·1—this immediately reduced the friction, provided the amount of the addition did not exceed a certain limit. For here a rather curious point occurred. If the addition was only a tenth of 1 per cent. of bismuth, it produced a slight reduction in the friction; if two-tenths of 1 per cent., rather more reduction; but if

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three-tenths of 1 per cent., up went the friction again under heavy loads; and by a series of experiments he had found, as shown previously by American experimenters, that about 0·25 per cent. of bismuth gave the best result; but from this proportion up to about 1 per cent. of bismuth the friction immediately became much higher than it was with the best percentage. He was now having a large number of alloys made up for the purpose of studying carefully the quantity of added impurity which produced the least friction. The results as far as they went were definite, and showed conclusively that, if the added metal were of larger atomic volume than bismuth, it still further reduced the friction, and still further increased the carrying power of the alloy. With such a metal of larger atomic volume than bismuth he had already succeeded in getting a white-metal alloy which had been kept running continuously for some days under a pressure of 2 tons per square inch at 550 revolutions per minute, and the temperature had not risen above 140° Fahr. with an exceedingly small amount of lubrication, namely 0·02 lb. of oil on a pad weighing 0·02 lb. This was certainly a remarkable result for white metal; and nothing else that he had yet met with would come anywhere near it. It showed indeed clearly the importance of getting absolute purity in the metals used for anti-friction alloys, that is, purity at least in the sense of keeping out metals of small atomic volume. With metals whose atomic volume did not differ much from that of the main body of the alloy, no material difference was found in the friction; but when the atomic volume did differ much there was a serious difference in the friction. The investigation was naturally a long one; he had already been occupied two years with it, and had obtained comparatively few results; but he hoped in a year or two to be able to place some highly interesting facts before the Institution, showing the effect of very small percentages of added impurities in alloys. He desired to congratulate Professor Roberts-Austen on the excellent work he had done, and to rejoice with him in it. From the three reports he had now presented it was abundantly evident how a purely scientific research had yielded results of practical value; and he believed it would yield still more in the future.

Mr. Bertram Blount noticed the statement in page 240, that in the experiments on molecular porosity gold was found not to be transmitted through the glass partition. In view of its atomic volume being as small as 10·2, he should have thought that it might pass through the galleries left by the elimination of the sodium atoms. Its failure to do so appeared to him at the first glance to be somewhat anomalous; but he had no doubt there was an adequate explanation, which he should be glad if the author would give.

The preparation of the electrolytic iron dealt with in page 244 appeared to him to have been carried out with extreme care and in a most sensible way. Hitherto some experimenters, especially in France, had been content to use electrolytic iron containing the gross amount of 0·08 per cent. of carbon. At the present time however, when the conviction prevailed that minute quantities of impurities could exercise a powerful influence upon the mass of the material containing them, such a percentage of carbon was altogether excessive; and any experiment conducted with electrolytic iron containing that amount of impurity would fall before the first criticism to which it was exposed. In the present instance the iron seemed to have been prepared in so careful a manner that no such objection could be raised to it. He should be glad therefore to know whether such pure iron displayed the usual properties of electrolytic iron, which he believed were usually ascribed to the presence of hydrogen; and whether it had a steely character, rather than that of pure iron obtained by a non-electrolytic method.

The alleged fall of the fusing point of cast-iron or steel on the addition of aluminium was shown in pages 246–7 to be a mistake; and the origin of the error he thought was adequately explained. Engineers would remember the prominence given some time ago to a material called "mitis" metal, and the statement that castings of unexceptionable quality could be made from that metal, which was said to be produced by the addition of aluminium to wrought-iron. The explanation now offered was that the metal when it was melted was more fluid, rather than that the alloy was more fusible. Was it not possible however that there might be another explanation? namely that the aluminium combining with the impurities present

(Mr. Bertram Blount.)

in the iron, notably with oxygen if any were there, liberated so much heat that the temperature of the whole mass was appreciably raised? If this idea, though possibly crude, were correct, the aluminium might act in much the same way as carbon or silicon did in an ordinary converter, the temperature of the whole mass being raised by the heat of combination of aluminium with oxygen, and possibly by the formation of an alloy, inasmuch as the formation of many aluminium alloys was exothermic, that is, attended with evolution of heat. Possibly some experiments had already been made in this direction, whereby the idea could be either refuted or substantiated.

As to the influence of bismuth on an alloy of lead, antimony, and tin (page 289), the difference between the atomic volume of lead 18·2, which was the principal constituent of the alloy, and that of bismuth 21·1, was not by any means particularly marked. It had been stated by Professor Goodman (page 290) that the addition of only 0·25 per cent. of bismuth to the alloy produced a large diminution of friction when the alloy was used as a bearing metal. While the matter was still under investigation, this statement must be accepted with reserve; but in the event of its corroboration it was a most remarkable proof that so minute an amount of impurity, even where the difference of its atomic volume from that of the main mass of the material was not great, nevertheless exercised an influence which was altogether out of proportion to its quantity.

Mr. Horace Darwin drew attention to a recent paper by Messrs. Heycock and Neville on the determination of high temperatures by means of platinum-resistance pyrometers (Journal of the Chemical Society, vol. 67, February 1895, pages 195–8), in which they gave temperatures somewhat differing from those quoted in page 270. Their temperature for the melting point of gold, for example, was 16° C. higher than here given; aluminium was 29° higher, tin 5° higher, and the boiling point of sulphur was nearly 4° C. lower. Their temperatures he could not doubt were substantially correct; and the question thus suggested itself whether there might possibly have been any errors in the instruments used in the present research.

The President regretted that Dr. Anderson, the chairman of the Alloys Research Committee to whom this Report had been presented by Professor Roberts-Austen, had found himself unable at the last to be present at the reading and discussion of the report, as he had intended to be. For himself he had to confess that he was one of those who had felt a kind of hesitation in the first instance about the practical bearing of the work represented by these reports. Now however that the reports had been presented, any hesitation had quite disappeared. No further proof he therefore thought was required of their usefulness than their fulness of suggestions respecting facts known and unknown, as to the probable causes of phenomena already observed, and as to the directions in which it might be useful for practical metallurgists to carry on their work. In face of these things there could no longer be any question in his own mind as to their representing the sort of work which might fairly be helped by this Institution. The subject of alloys was one which no doubt many engineers were working at. Only today for instance he had tested an alloy, which had all the appearance of being a copper alloy, but which had a tenacity of over 40 tons per square inch, and an elongation which would have done credit to any steel of that tenacity. It had been arrived at, he presumed, by great skill and sound knowledge on the part of the maker; and it was obviously just this sort of knowledge which engineers were now deriving from the work Professor Roberts-Austen was carrying on for this Institution. He was sure it would be interesting to the Members to know that the Société d'Encouragement of Paris had awarded one of their highest prizes to the author of these Reports, in great measure in recognition of the value of the work he had done for the Alloys Research Committee.

The applause with which this announcement was received by the meeting he would take as signifying their agreement in a hearty vote of thanks to Professor Roberts-Austen, and also to Mr. Gibb, Mr. Stansfield, and Mr. Reginald Roberts, for the work represented by the present Report and Appendices.

Professor Roberts-Austen said all he asked was to be allowed to go on working at this important research.

With Messrs. Heycock and Neville's paper (page 292) he was familiar, and would often gladly have used the platinum-resistance thermometer, had he been able to afford it. But when it became a question of putting a platinum thermometer into a tiny nugget of gold, like that he had here been experimenting with, it was almost impossible to do so; it had often been necessary to work with a quantity of alloy too small even to cover the face of their thermometer. In using the thermo-junction however, about an eighth of an inch of the twisted platinum and platinum-rhodium wires was all that had to be dipped into the molten globule; and if the end got accidentally broken or melted off, it did not inconvenience the experiment beyond the momentary interruption. Possibly some of the work which had only been roughed out by this means might have to be gone through again, and refined by more delicate instruments, though he was not quite sure that it would be so. At any rate he had worked with Mr. Callendar for some little time with his modification of the Siemens pyrometer, and the results they got agreed closely with those he had himself obtained with the thermo-junction. Moreover he did not quite know how the platinum-resistance thermometer could be connected with the autographic recorder, which after all was the essential point. The remarkable facility with which photographic records could be got by the use of these small thermo-junctions was one of his chief reasons for adopting them. It remained to be seen how far the results thus obtained were directly comparable with such standard work as that of Messrs. Heycock and Neville.

Mr. Robert A. Hadfield wrote that, though all of Professor Roberts-Austen's conclusions might not be accepted by other investigators, he had unquestionably indicated the direction in which further knowledge was to be looked for, and had also found means

whereby to attain it. Only last month, in an interesting lecture at the Royal Institution, he had given many hints which would be of great value in the prosecution of further research.

In the present report it is stated (page 245) that in the examination of the series of iron-aluminium alloys the composition of each sample was determined subsequently; and this information is of importance for enabling the character of the several alloys to be properly judged.

In page 246 the writer is glad to see so strongly confirmed the statements made in his own paper on aluminium steel, read before the Iron and Steel Institute in 1890 (Journal 1890, page 161). At that time it was generally supposed that by so small an admixture as only one-tenth of one per cent. of aluminium the melting point of iron was lowered several hundred degrees. His own observations led him to believe that this supposition was without foundation; and by means of the Le Chatelier pyrometer his belief was confirmed by M. Osmond, who clearly proved that an alloy furnished to him by the writer, containing 94·5 per cent. of iron and 5 per cent. of aluminium, did not show the slightest signs of fusion until a temperature of 1,475° C. or 2,687° F. was reached. Mild steel examined at the same time fused at 1,500° C. or 2,730° F. The error then prevalent was thus corrected.

In page 248 it is stated that alloys containing about 90 per cent. of iron and 10 per cent. of aluminium appear to be tough and strong; whereas the writer's own experiments, given in detail in his paper above referred to, proved conclusively that additions of aluminium, like those of silicon, when exceeding about 2 or 2½ per cent., conferred brittleness upon iron alloys which were practically free from carbon or very low in that element, and the brittleness increased with the increasing percentage of aluminium or silicon. Thus sample No. 1,167 I, containing 5·6 per cent. of aluminium and only 0·22 per cent. of carbon, was exceedingly brittle either in the cast or in the forged state; in the latter state its tensile strength was 38 and 36 tons per square inch, with an elongation of 3·67 and 6·45 per cent. respectively, when unannealed and when annealed. The next sample No. 1,167 J, containing 9·14 per cent.

(Mr. Robert A. Hadfield.)

of aluminium, could not be forged at all, and was exceedingly brittle as cast. It is therefore difficult to understand how the alloys mentioned in page 248 can be either tough or strong.

The conclusion recorded in page 251 the writer presumes is intended to apply to the pure metals themselves. Unfortunately there are at present but few data respecting the physical properties of the pure metals. Whilst therefore pure metals with high melting points may have high tenacities, and conversely, yet this does not apply to certain alloys, if carbon-steel may be so termed; for the higher the percentage of carbon up to a certain amount—probably up to 0·8 or 1·0 per cent.—the higher is the tenacity, but the lower without doubt is the melting point. The same is the case with manganese steel, which has been proved to possess a lower melting point than ordinary steel, although in its forged and toughened condition its tenacity is over 60 tons per square inch with an elongation of over 40 per cent.

In the appendix by Mr. Stansfield, which will be found to be of great service, the suggestion is most valuable (paragraph 4 of summary, page 279) as to the existence of special groups, which he has so well chosen, of the constituent elements. It does indeed seem to offer a satisfactory explanation of some of the peculiar facts noticed in the behaviour of alloys. Perhaps the author has no idea of applying this suggestion to iron alloys; and for certain of the steel alloys at any rate it is not possible to accept it at present in the absence of fuller evidence. Manganese steel for instance, which in this respect differs entirely from all other iron alloys tested by the writer, resembles bronze alloys in becoming toughened instead of hardened by water-quenching; yet it cannot be said, from evidence at present available, that the more fusible part of the alloy melts first, and by being made to solidify quickly causes fineness of grain. The toughening by water-quenching commences in manganese steel at a comparatively low temperature.

The interesting remarks on annealing (page 277), which are presented in a form new to the writer, certainly open a wide field for research; and he trusts Mr. Stansfield will continue his practical and valuable work.

Professor Roberts-Austen considered that Mr. Hadfield was quite correct in his reference (page 295) to the alloys of iron and aluminium which contained 90 per cent. of iron. The expression used in the report (page 248) should have indicated that they were relatively strong.

LOCOMOTIVE BUILDING IN JAPAN.

By Mr. RICHARD F. TREVITHICK,
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The first Locomotive built in Japan, No. 221, is also the first Compound Locomotive employed in this country. Its general appearance and construction are shown in Plates 48 to 56. It was turned out of the Kobe shop on 26th May 1893, and has worked continuously ever since without giving trouble in any way, and with a mileage of a little over 33,700 during the fifteen months to 31st August 1894. In respect of efficiency, it takes its turn with any other main-line engine, and has always done the work with a smaller consumption of coal, as shown by the comparative statement in Table 1 appended of the working of this engine and of an imported non-compound locomotive No. 88 during eight months' running in competition with each other. It has not been found to require more steam-shed repairs than the non-compound engines, and has never occasioned delay to the traffic from any cause; and the fact that it has not yet been necessary to send it to the shops for general repairs gives reason to believe that its mileages between general overhauls will not be inferior to those of any other class of main-line engines. In first cost it is by far the cheapest main-line engine on the Imperial Government Railways of Japan, having cost £1,350; and the particulars of the first cost of this and other engines are given in Table 2.

The construction of this engine on the writer's initiative and from his designs was sanctioned as an experiment, subject only to the condition that a tank engine was to be built. That the experiment is considered by the railway administration to have been brought to a successful issue is sufficiently proved by the

sanction given for a repetition on a larger scale, namely for the construction of eight non-compound tender locomotives, which are now being built.

Leading Dimensions.—The following are the leading dimensions of this outside-cylinder compound tank locomotive, No. 221, the gauge of the Imperial Government Railways of Japan being 3 feet 6 inches; see Plates 48 to 56. High-pressure cylinder 15 inches diameter and 20 inches stroke; steam ports 12 inches × $1\frac{3}{8}$ inch, exhaust port 12 inches × $2\frac{3}{4}$ inches; Trick phosphor-bronze slide-valve, lap $1\frac{1}{8}$ inch, inside clearance $\frac{1}{4}$ inch, maximum travel $4\frac{5}{16}$ inches full, lead constant 1-16th inch = 1-8th inch with ordinary valve. Low-pressure cylinder $22\frac{1}{2}$ inches diameter and 20 inches stroke; steam ports 16 inches × $1\frac{5}{8}$ inch, exhaust port 16 inches × $3\frac{1}{4}$ inches; Trick phosphor-bronze slide-valve, lap 15-16ths inch, inside clearance nil, maximum travel $4\frac{1}{4}$ inches, lead constant 1-16th inch = 1-8th inch with ordinary valve. Intermediate receiver double the capacity of the high-pressure cylinder. Joy's radial valve-motion for both valves. Single slide-bars; wearing surface of cross-head slides 45 square inches. Boiler shell made of best Yorkshire iron plates $\frac{1}{2}$ inch thick; inside fire-box of best Yorkshire iron plates 7-16ths inch thick, except copper tube-plate $\frac{3}{4}$ inch thick where pierced for tubes and $\frac{1}{2}$ inch thick below; barrel 45 inches inside diameter throughout; distance between tube-plates 9 feet $9\frac{1}{4}$ inches. Crown sheet of fire-box stayed with 72 Yorkshire iron stays of $\frac{7}{8}$ inch diameter, having ends enlarged for thread to be cut with 1-inch die. Brass tubes, 157 in number, thickness No. 12 B.W.G. = 0·110 inch, external diameter $1\frac{3}{4}$ inch at fire-box end and $1\frac{13}{16}$ inch at smoke-box end, pitch $2\frac{3}{8}$ inches. Heating surface in tubes 703·36 square feet, in fire-box above foundation ring 66·21; total 769·57 square feet. Grate area 12·4 square feet. Working pressure 150 lbs. per square inch. Eight wheels, four coupled 53 inches diameter with tires 3 inches thick; coupled-wheel axles of steel, with journals 8 inches long by $6\frac{1}{2}$ inches diameter, and gun-metal axle-boxes without loose steps. Leading and trailing radial wheels 38 inches diameter with tires 3 inches thick; axles of best

Yorkshire iron with journals $8\frac{1}{2}$ inches long by 6 inches diameter, fitted with Webb's radial axle-boxes. Adjusting screws of all bearing springs in tension. Extreme wheel-base $19\frac{1}{2}$ feet, rigid wheel-base $7\frac{1}{2}$ feet. Weight of engine in working order 40 tons; available for traction $21\frac{1}{2}$ tons. Capacity of water tanks 987 gallons. Weight of coal usually put on engine 25 cwts.

The non-compound engine No. 88 imported from England, which was run in competition with No. 221 compound, has cylinders 14 inches diameter and 20 inches stroke; steam ports 12 inches × $1\frac{1}{4}$ inch, exhaust port 12 inches × $2\frac{3}{4}$ inches; ordinary slide-valves, lap $\frac{3}{4}$ inch, inside clearance nil, maximum travel $3\frac{3}{16}$ inches, lead constant $\frac{1}{8}$ inch. Joy's radial valve-motion. Two slide-bars to each cylinder; wearing surface of cross-head slides 52 square inches. Boiler shell of best Yorkshire iron plates 7-16ths inch thick; inside fire-box of copper plates $\frac{1}{2}$ inch thick, with copper tube-plate of same thicknesses as in the compound No. 221; barrel telescopic, smallest inside diameter 43 inches, largest $44\frac{3}{4}$ inches; distance between tube-plates 9 feet $8\frac{1}{4}$ inches. Crown sheet of fire-box stayed by six roof bars, attached to shell and to crown sheet in usual manner. Brass tubes, 147 in number, of exactly same thickness, diameter, and pitch as in compound. Heating surface in tubes 653 square feet, in fire-box above foundation ring $64\frac{1}{2}$; total $717\frac{1}{2}$ square feet. Grate area 12 square feet. Working pressure 140 lbs. per square inch. Eight wheels, four coupled 52 inches diameter with tires $2\frac{1}{2}$ inches thick; coupled-wheel axles of steel, with journals 7 inches long by 6 inches diameter, and steel axle-boxes with loose steps; adjusting screws of driving springs in compression. Leading and trailing radial wheels 37 inches diameter with tires $2\frac{1}{2}$ inches thick; axles of steel, with journals $8\frac{1}{2}$ inches long by 5 inches diameter, fitted with Webb's radial axle-boxes; adjusting screws of bearing springs in tension. Extreme wheel-base $19\frac{1}{2}$ feet, rigid wheel-base $7\frac{1}{2}$ feet. Weight of engine in working order 35 tons; available for traction $20\frac{1}{2}$ tons. Capacity of water tanks 1,000 gallons. Weight of coal usually put on engine 25 cwts.

The particulars of the valve setting of the two engines are given in Tables 3 and 4 appended. Those of No. 221 compound

were taken from the engine when it was turned out of the shop; in forward gear the usual angles of the quadrant when running trains are 14° and 13° and 12°; in backward gear the engine has scarcely ever had to run a train. The particulars of No. 88 non-compound were taken from the maker's tracing.

The road over which these engines—No. 221 compound and No. 88 non-compound—have been worked is fairly level with three ruling gradients of 1 in 100, none of which exceeds three-quarters of a mile in length. The sharpest curves, four in number, on the portion of the line over which No. 221 has worked, are of 20 chains radius, and each of them is about a quarter of a mile long. There is one curve of 36 chains radius; and the others are of 40 chains radius and upwards. One of the 20-chain curves is on a gradient of 1 in 100; the others are on practically level road.

Particulars of Building at Kobe Works.—Two frame-plates of mild Siemens-Martin steel were obtained from England, planed on both sides, and shaped on edges to tracings sent from Japan; all holes and gaps for horn-blocks were drilled or cut out in Kobe. Four steel plates forming the radial axle-box guides were sent out from England, flanged and bent to required radius in conformity with tracing supplied from Japan. The remainder of the material required for constructing the frame was supplied from the store, out of the ordinary stock of iron plates, bars, and angles.

Four straight axles, two of best Yorkshire iron and two of best Siemens-Martin steel, and eight steel tires, were sent out from England as supplied from forge or steel works; all turning and fitting were done in Kobe. The wheels, eight in number, were forged in Kobe from scrap iron, and formed the crucial job in smith work. All tires now used on these railways are of steel; they are made in England, sent out as received from the steel works, and bored out and finished as required in Japan.

The valve gear, spring gear, brake gear, draw-bar hooks and attachments were made in Kobe, almost entirely from scrap iron. Springs were made from steel out of stores. The buffers were made partly of Yorkshire iron plate, and partly of scrap iron.

The piston-rods were made of round steel supplied from store, but the cross-heads were made of scrap iron. The low-pressure piston of steel was sent out from England as received from the steel works; all turning and fitting were done in Kobe. The high-pressure piston being of cast-iron was made in Kobe. The slide bars were made of steel bars out of stock. The connecting rods and coupling rods were forged from 6-inch square bars of best Yorkshire iron; the crank pins from 6-inch diameter round bars of same quality.

The cylinders, axle-boxes, and all other fittings of cast-iron or brass were cast and finished complete in the Kobe shops.

The boiler was made of plates, bars, and angles of best Yorkshire iron supplied from store, all flanging &c. being done in the shops. The foundation ring and fire-hole ring were made from scrap iron. All copper tube-plates used in Kobe for boiler making or repairs are ordered from England of best quality; the flanging is entirely done in Kobe, after which the tube and rivet holes are drilled. The dome with its seating was obtained from England, though not specially ordered for this engine. All boiler mountings were made in Kobe. Tanks, coal bunkers &c. were made of best best Staffordshire plates and angles from stock. Besides the dome and its seating, the only finished pieces from abroad put into this engine are one Bourdon pressure-gauge, one vacuum-brake ejector, one vacuum-brake duplex pressure-gauge, and one vacuum-oil sight-feed lubricator. All boiler tubes used in Japan are of course imported; likewise the bulk of the piping, both copper and iron, required in a locomotive; and india-rubber springs &c.

It will thus be seen that in this job the builders have done nearly every part of the work it was possible for them to undertake unless possessed of ironworks. The workmanship, both in detail and in the engine as a whole, leaves nothing to be desired, and compares favourably with that of the best engines imported. The significance of this result is emphasized when it is understood that it is entirely the product of Japanese labour led by Japanese foremen, no foreign foremen being employed in the Kobe workshops.

The position of the compound system for locomotives in Japan is at present merely that of trial. The view entertained after the first fifteen months' working of No. 221 compound, that there was no reason to believe it would prove costly in maintenance, has been confirmed by subsequent experience. On 2nd October 1894, after sixteen months' running with a mileage of 35,573, the engine was sent to the repairing shop for wheel turning, and a few other small repairs were then executed. On 6th October it was again put to work, and by 31st May 1895 had brought its mileage up to 57,473. It has not been found that any of the non-compound engines do better.

The Government Railways led the way by building this compound locomotive. Two private railways shortly afterwards followed suit by each purchasing one or two four-cylinder compound locomotives on the Vauclain system from the Baldwin Locomotive Works, Philadelphia, Pennsylvania; and finally in August 1894 the Japan Railway put in traffic a couple of two-cylinder compounds built by Messrs. Neilson and Co. of Glasgow. The Baldwin engines, for which possibly too much was claimed, have not quite realized all that was expected of them, nor have they in any way disparaged the locally built engine. Some particulars of the working of these four-cylinder compounds are given in Table 5 in comparison with No. 221 two-cylinder compound and No. 179 non-compound; the latter is a duplicate of No. 88 non-compound, and was the first engine worked against No. 221 compound.

It will thus be seen that a locomotive has been built in Japan, which in first cost and efficiency will bear comparison with imported locomotives; and also that Japan, possessing cheap labour and coal, may at no distant date find it unnecessary to go to foreign makers for her locomotives.

TABLE 1.

Comparative Working of Compound and Non-compound Locomotives during eight months ending 31 *August* 1894.

Radial tank engine with four wheels coupled		No. 221 Compound.	No. 88 Non-compound.
Engine miles, total	miles	15,672	15,603·6
Number of vehicles per train, average		16·43	15·73
Weight of train including load, average, tons		122·07	118·65
Ton-miles, total	ton-miles	1,913,081	1,851,367
Coal Consumption.		Lbs.	Lbs.
Working trains, total		301,008	346,397
Getting up steam, total		47,301	40,758
Total coal consumption		348,309	387,155
Working trains, per engine mile	*a*	19·21	22·20
Total consumption per engine mile	*b*	22·22	24·81
Working trains, per ton-mile	*c*	0·1573	0·1871
Total consumption per ton-mile	*d*	0·1821	0·2091
Ton-miles per ton of total coal	ton-miles	12,301	10,713
Increase of ton-miles by Compound		14·82 per cent.	
Saving by Compound, line *a*		13·47 per cent.	
,, ,, ,, ,, *b*		10·44 per cent.	
,, ,, ,, ,, *c*		15·93 per cent.	
,, ,, ,, ,, *d*		12·91 per cent.	

The train service from and to Kobe consists of passenger, mixed, and goods trains. Engines Nos. 221 and 88 were worked against each other with all three kinds of trains. Of the 15,672 miles run by the compound No. 221 during the eight months, 9,436 were with passenger trains, 2,447 with mixed, and 3,789 miles with goods trains. Exclusive of engine, the weight of a passenger train ranged from a minimum of 41 tons to a maximum of 151, and averaged 90 tons; a mixed train from 74 to 212, averaging 138 tons; and a goods train from 40 to 318, averaging 135 tons. These mileages and weights are from the record of No. 221 compound; but for any practical purpose they apply equally to No. 88 non-compound. Passenger and mixed trains run to the same time-table; goods trains are timed rather slower. On the section of line worked over by these two engines the stations are approximately five miles apart; and the time allowed requires passenger trains to maintain between stations a uniform speed of about 22 miles per hour, and goods trains about 16. Whence it follows that, in order to keep time, a heavy train has to attain a higher speed than a light one, so as to make up for time lost in starting and stopping. In order to diminish the trouble of obtaining the above comparative statement, the engines were never told off for shunting. No allowance was made for the little shunting sometimes required at roadside stations, putting off or taking on wagons; and therefore engine-miles and train-miles are the same in amount. The reason why the coal used in getting up steam has been kept separate from that used in actually working the trains is that No. 221 compound invariably required more coal to get up steam than did No. 88 non-compound, owing to No. 221 having a slightly larger boiler; and in this way 3 per cent. of its working economy was sacrificed. Steam is more easily kept up in No. 221 compound than in No. 88 non-compound, especially when the load is heavy. The coal used on the Japanese railways is all mined in this country. It is very suitable for locomotives, and complaints are rare of engines steaming badly. The present cost of coal at the Kobe end of the line is about 5·39 yen per ton; at the present exchange value of the silver yen, which is generally rather less than two shillings, this cost is equivalent to rather less than 10*s.* 9*d.* a ton.

TABLE 2.

First Cost of Compound and Non-compound Locomotives.

The first cost of No. 221 Compound built at Kobe was 8,992 yen, made up as follows, a silver yen being then worth three shillings:—

	$		£
Material	5,337	=	801
Labour	2,930	=	440
Coal, oil, coke, and other small stores, cost of working shop engines overtime, &c . .	663	=	99
Drawing-office materials	62	=	9
Total . .	$8,992	=	£1,349

Recently three Non-compound radial tank engines, similar to No. 88, cost £1,550 each free on board in an English port. Freight, insurance, and other charges brought the cost of each engine up to £1,713 on board in Kobe. Adding 5 per cent. duty on £1,550, amounting to £77 10*s*., and cost of landing and placing in Kobe locomotive yard, amounting to £1 10*s*., the cost is raised to £1,792. The engines had then to be taken out of their packing cases, erected, and painted; so that by the time they were put into traffic £1,800 would be about the cost of each. There is thus a difference of £450 in favour of the engine built in Japan. The radial tank engines are the smallest main-line engines now used on these railways, and therefore the least expensive in first cost.

The construction of No. 221 Compound did not entail the least alteration or addition to the Kobe workshop plant, nor the employment of a single extra workman of any kind. Whenever it seemed at all likely to encroach on the requirements of the routine work, inconvenience was avoided by overtime; and the cost of the extra running of machinery was charged against the new engine, as in the above statement.

TABLE 3.—*Valve Setting in No. 88 Non-compound Locomotive, taken from maker's tracing.*

Lead constant at both ends 1-8th inch.

Maximum Opening of Steam Port	Back 13-16ths inch Front 7-8ths inch	in Forward gear.
	Back 31-32nds inch Front 11-16ths inch	in Backward gear.

FORWARD GEAR. Percentage of stroke.						BACKWARD GEAR. Percentage of stroke.					
Cut-Off.			Release.			Cut-Off.			Release.		
Back.	Front.	Diff.	Back.	Front.	Diff.	Back.	Front.	Diff.	Back.	Front.	Diff.
P.c.	P.c.	P.c.	P.c.	P.c.	P.c.	P.c.	P.c.	P.c.	P.c.	P.c.	P.c.
75	75	0	$92\frac{1}{2}$	$92\frac{1}{2}$	0	$71\frac{1}{2}$	75	$3\frac{1}{2}$	90	93	3
71	70	1	91	$91\frac{1}{2}$	$\frac{1}{2}$	$66\frac{1}{2}$	70	$3\frac{1}{2}$	$88\frac{1}{2}$	$91\frac{1}{2}$	3
61	60	1	87	88	1	$58\frac{1}{2}$	60	$1\frac{1}{2}$	85	$88\frac{1}{2}$	$3\frac{1}{2}$
49	50	1	$82\frac{1}{2}$	$83\frac{1}{2}$	1	49	50	1	81	84	3
39	40	1	$77\frac{1}{2}$	79	$1\frac{1}{2}$	$40\frac{1}{2}$	40	$\frac{1}{2}$	$76\frac{1}{2}$	$79\frac{1}{2}$	3
$29\frac{1}{2}$	30	$\frac{1}{2}$	72	$73\frac{1}{2}$	$1\frac{1}{2}$	31	30	1	$71\frac{1}{2}$	74	$2\frac{1}{2}$
$19\frac{1}{2}$	20	$\frac{1}{2}$	65	66	1	22	20	2	66	$67\frac{1}{2}$	$1\frac{1}{2}$

TABLE 4.—*Valve Setting in No. 221 Compound Locomotive, taken from engine when turned out of shop.*

Lead, with Trick valve :—
High-p. cyl. in both gears, 1-16th inch at both ends;
Low-p. cyl. { forward gear { 1-16th inch at back end, 3-32nds inch at front end, backward gear 3-32nds inch at both ends.

Gear.	Cylinder.	Angle of Quadrant.	Travel of Valve.	Maximum Opening of Steam Port. Back.	Maximum Opening of Steam Port. Front.	Percentage of stroke. Cut-off. Back.	Cut-off. Front.	Release. Back.	Release. Front.	Compression. Back.	Compression. Front.
			Inches.	Inch.	Inch.	P. c.	P. c.	P. c.	P. c.	P. c.	P. c.
FORWARD GEAR.	HIGH-Pressure Cyl.	20°	$4\frac{5}{16}$	1	$1\frac{1}{8}$	$74\frac{1}{2}$	$73\frac{3}{4}$	90	88	95	96
FORWARD GEAR.	HIGH-Pressure Cyl.	18°	4	7–8	*f* 1	70	$69\frac{1}{2}$	*b* 88	$87\frac{1}{4}$	$94\frac{1}{4}$	$94\frac{1}{2}$
FORWARD GEAR.	HIGH-Pressure Cyl.	16°	$3\frac{3}{4}$	11–16	*b* 7–8	$62\frac{1}{2}$	$64\frac{1}{4}$	$85\frac{1}{2}$	85	*f* 93	93
FORWARD GEAR.	HIGH-Pressure Cyl.	†14°	*b* $3\frac{7}{16}$	9–16	5–8	$55\frac{1}{2}$	57	82	82	$91\frac{1}{2}$	$91\frac{1}{2}$
FORWARD GEAR.	HIGH-Pressure Cyl.	†13°	$3\frac{5}{16}$	1–2	9–16	52	$54\frac{1}{2}$	*f* 79	*f* 80	$90\frac{1}{2}$	$90\frac{1}{2}$
FORWARD GEAR.	HIGH-Pressure Cyl.	†12°	*b* $3\frac{3}{16}$	7–16	1–2	48	51	$78\frac{1}{4}$	79	90	90
FORWARD GEAR.	HIGH-Pressure Cyl.	11°	$3\frac{1}{16}$	3–8	7–16	*b* 44	*f* 47	76	77	*b* 89	*b* 89
FORWARD GEAR.	HIGH-Pressure Cyl.	10°	$2\frac{15}{16}$	5–16	3–8	38	$42\frac{1}{4}$	74	75	$87\frac{3}{4}$	$87\frac{1}{4}$
FORWARD GEAR.	LOW-Press. Cyl.	20°	$4\frac{1}{4}$	*b* $1\frac{1}{8}$	$1\frac{5}{16}$	80	$79\frac{1}{2}$	94	$94\frac{3}{4}$		
FORWARD GEAR.	LOW-Press. Cyl.	18°	*f* $3\frac{7}{8}$	*b* 1	$1\frac{1}{8}$	*f* 75	76	$93\frac{1}{2}$	$92\frac{1}{2}$		
FORWARD GEAR.	LOW-Press. Cyl.	16°	$3\frac{5}{8}$	*b* 13–16	*b* 1	*b* 71	72	92	91		
FORWARD GEAR.	LOW-Press. Cyl.	†14°	$3\frac{1}{4}$	*b* 11–16	*f* 3–4	65	$66\frac{3}{4}$	*b* 89	$90\frac{1}{4}$		
FORWARD GEAR.	LOW-Press. Cyl.	†13°	*b* $3\frac{1}{8}$	*b* 5–8	*f* 11–16	$62\frac{1}{2}$	63	*b* 88	*f* 89		
FORWARD GEAR.	LOW-Press. Cyl.	†12°	3	9–16	5–8	$60\frac{3}{4}$	$60\frac{1}{2}$	*b* 87	88		
FORWARD GEAR.	LOW-Press. Cyl.	11°	$2\frac{7}{8}$	1–2	9–16	53	$56\frac{1}{2}$	85	87		
FORWARD GEAR.	LOW-Press. Cyl.	10°	$2\frac{3}{4}$	7–16	1–2	49	$52\frac{1}{2}$	83	*f* 85		
* BACKWARD GEAR *	HIGH-Press. Cyl.	20°	*f* $4\frac{3}{16}$	*f* $1\frac{1}{8}$	*b* 7–8	$69\frac{3}{4}$	74	$86\frac{3}{4}$	$90\frac{3}{4}$	$96\frac{1}{2}$	$93\frac{1}{4}$
* BACKWARD GEAR *	HIGH-Press. Cyl.	18°	*f* $3\frac{11}{16}$	*f* 1	3–4	$65\frac{3}{4}$	$69\frac{1}{2}$	$84\frac{1}{4}$	89	*b* 96	92
* BACKWARD GEAR *	HIGH-Press. Cyl.	16°	*b* $3\frac{5}{8}$	13–16	5–8	60	63	$81\frac{1}{2}$	$86\frac{3}{4}$	$93\frac{3}{4}$	91
* BACKWARD GEAR *	HIGH-Press. Cyl.	14°	*f* $3\frac{5}{16}$	5–8	*b* 1–2	55	$55\frac{1}{4}$	*b* 79	$83\frac{1}{2}$	93	*b* 89
* BACKWARD GEAR *	HIGH-Press. Cyl.	13°	*b* $3\frac{3}{16}$	*b* 5–8	7–16	50	50	*b* 78	$81\frac{1}{2}$	91	88
* BACKWARD GEAR *	HIGH-Press. Cyl.	12°	*f* $3\frac{1}{16}$	1–2	*f* 3–8	$45\frac{1}{2}$	$46\frac{1}{2}$	76	79	$89\frac{1}{2}$	*f* 87
* BACKWARD GEAR *	HIGH-Press. Cyl.	11°	*b* 3	7–16	5–16	$41\frac{1}{2}$	$42\frac{3}{4}$	*b* 73	$76\frac{1}{4}$	*f* 89	*f* 86
* BACKWARD GEAR *	HIGH-Press. Cyl.	10°	*b* $2\frac{7}{8}$	*f* 5–16	*f* 1–4	*f* 38	*b* 38	$70\frac{1}{4}$	$74\frac{1}{4}$	$87\frac{1}{4}$	84
* BACKWARD GEAR *	LOW-Pressure Cyl.	20°	$4\frac{1}{8}$	*b* $1\frac{7}{16}$	*b* 15–16	$76\frac{1}{4}$	$78\frac{3}{4}$	92	$94\frac{1}{2}$		
* BACKWARD GEAR *	LOW-Pressure Cyl.	18°	$3\frac{13}{16}$	$1\frac{3}{16}$	*f* 3–4	$72\frac{1}{4}$	$74\frac{1}{2}$	$90\frac{1}{2}$	$93\frac{1}{4}$		
* BACKWARD GEAR *	LOW-Pressure Cyl.	16°	$3\frac{7}{16}$	1	11–16	$67\frac{3}{4}$	$69\frac{3}{4}$	$88\frac{1}{2}$	92		
* BACKWARD GEAR *	LOW-Pressure Cyl.	14°	$3\frac{1}{8}$	*f* 3–4	*b* 9–16	62	$61\frac{1}{2}$	$86\frac{1}{2}$	*f* 89		
* BACKWARD GEAR *	LOW-Pressure Cyl.	13°	3	11–16	*b* 1–2	$58\frac{1}{2}$	58	$85\frac{1}{4}$	$88\frac{1}{2}$		
* BACKWARD GEAR *	LOW-Pressure Cyl.	12°	$2\frac{7}{8}$	5–8	7–16	55	*f* 53	$83\frac{3}{4}$	*f* 87		
* BACKWARD GEAR *	LOW-Pressure Cyl.	11°	$2\frac{3}{4}$	1–2	*f* 3–8	$50\frac{1}{4}$	49	$82\frac{1}{4}$	85		
* BACKWARD GEAR *	LOW-Pressure Cyl.	10°	*b* $2\frac{5}{8}$	7–16	5-16	$46\frac{1}{4}$	*f* 44	$80\frac{1}{2}$	83		

* Engine has scarcely ever had to run a train in backward gear.

† 14° and 13° and 12° are the usual angles of quadrant when running trains.
f = full. *b* = bare.

TABLE 5.—*Comparative Working of Compound and Non-compound Locomotives on Imperial Government Railways and Chikuho Kogyo Tetsudo Kaisha Railway.*

Name of Railway		Imperial	Imperial	Chikuho	Chikuho	Chikuho
Number of Engine		221	179	9	8	7
Compound or Non-compound		Compound	Non-comp.	Compound	Non-comp.	Non-comp.
Where built		Japan	England	America	America	America
Engine miles, total	miles	6403·5	6390·5	3259·3	2874·0	3228·6
Number of vehicles per train, average		12·89	13·24	26·81	23·80	25·67
Weight of train including load, average	tons	94·36	94·71	180·70	165·20	172·40
Ton-miles, total	ton-miles	604,203	605,272	588,956	474,785	556,611
Coal Consumption, total	lbs.	121,170	138,445	135,200	124,020	145,530
" " per engine-mile	lbs.	18·92	21·66	41·48	43·15	45·08
" " per ton-mile	lb.	0·2005	0 2287	0·2296	0·2612	0·2615
Ton-miles per ton of total coal	ton-miles	11,172	9,794	9,756	8,576	8,566
Increase of ton-miles over Chikuho No. 7	per cent.	30·42	14·34	13·89	0·12	—

No. 179 is a duplicate of No. 88 non-compound, and was the first engine worked against No. 221 compound. No. 9 is a four-cylinder compound, having two high-pressure cylinders 11 inches diameter, and two low-pressure 19 inches diameter, all 22 inches stroke; six coupled wheels 4 feet diameter; heating surface 1,379 square feet; grate area 21 square feet. Nos. 8 and 7 non-compounds have cylinders 17 inches diameter and 22 inches stroke; and agree with No. 9 in the other particulars given. All three American engines—Nos. 9, 8, 7—are from the Baldwin Locomotive Works, and all have 29½ tons on drivers, and their working pressure is said to be 140 lbs. per square inch. A duplicate engine of No. 9 four-cylinder compound from the Baldwin Locomotive Works was borrowed from the Sanyo Railway, and tried on the gradients of 1 in 40 on a section of the Government Railways between Kioto and Baba; in full gear and with the pressure gauge showing 175 lbs. per square inch it took with difficulty over this section a train of 158 tons exclusive of engine, at a speed of only about five miles an hour.

MEMOIRS.

William James Armitage was born at Brighton on 16th July 1819, and was brought up chiefly in France, where he lived for seventeen years and took his degree at the Paris University. He began by studying medicine and then took to painting, until in 1855 he joined his father Mr. James Armitage and his uncle Mr. William Armitage, who ten years previously had founded the Farnley Iron Works, Leeds. From that time he was closely connected with these works in one capacity or another, and took a leading part in the Best Yorkshire Iron trade. For the last twenty years he was not actively engaged in the management, although he was chairman of the company and frequently visited the works. For many years he was a director of the firm of Messrs. Blair and Co., marine-engine builders of Stockton-on-Tees, his father having been one of the founders of that concern. For a considerable time also he was associated with Messrs. Brown, Bayley and Co., Sheffield. He bought this concern, and carried it on himself for some years, and in 1888 sold it to the present company, of which he became chairman, retaining a large share in the business. Though never brought up as an engineer, he had acquired a large amount of engineering experience in the management of the works with which he was connected, which dealt almost entirely with raw materials, and had not much to do with turning out the finished products of engineering. His death took place at Brighton on 12th August 1895 at the age of seventy-six. He became a Member of this Institution in 1859.

Samuel Gordon Brebner was born in Aberdeen, on 18th June 1848. In January 1860 he was apprenticed to Messrs. Kirk and Perry, building contractors, and was engaged in the erection of several large buildings in London, Brighton, Dover, Portsmouth, &c.

In August 1864 he entered the Royal Arsenal at Woolwich, where he served an apprenticeship in the machine shops of the Royal Laboratory until December 1869, during which period he assisted in the erection and repairs of engines and boilers, both on shore and of steamers calling there for that purpose. Subsequently he was employed in the erection of machinery at Brentford, Middlesex; and was finally engaged by the Secretary of State for India in August 1871 to proceed to Kirkee, Bombay Presidency, in connection with the erection of the whole of the plant of the Small-Arms Ammunition Factory. In February 1873 he was appointed principal foreman, which position he held for nine years; in 1882 he became first assistant mechanical engineer, and in 1883 chief mechanical engineer. Since then he received the thanks of the government, and on three occasions an honorarium for his inventions. He took an active part in the volunteer movement, having been a member of the Poona Corps from its commencement in 1877, and was captain of the Kirkee company. In March 1893 he left India on a year's deputation to Woolwich Arsenal, in connection with the manufacture of Lee-Metford ammunition. His services were subsequently placed at the disposal of the superintendent of the gunpowder factory in connection with the manufacture of cordite; but his failing health prevented his going through the course of training at Waltham Abbey. He therefore retired from the service on 16th March 1895, after having been appointed by the Secretary of State for India on 4th October 1894 chief mechanical engineer of the new explosives factories in Kirkee. After a long and painful illness his death took place at Charlton, Kent, on 6th June 1895, in the forty-seventh year of his age. He became a Member of this Institution in 1889.

Richard Elihu Dickinson was born in Liverpool on 16th April 1849. He was there apprenticed to a shipping firm which is now merged into the White Star line; and received a good commercial grounding. His tastes however inclined to mechanical engineering, which he studied both theoretically and practically. At the age of twenty-two he commenced business as an engineer and ironfounder at the Cleveland Engine Works, Birkenhead, where

he constructed overhead cranes and special machinery. At that time he became connected with some Portuguese mines, and was resident abroad for a time, erecting the necessary machinery. Turning his attention early to the application of steam power to tramway cars, he built a considerable number, which were used in Dublin, Wigan, and elsewhere; their advantage lay in the absence of smoke, and the small consumption of fuel. Closing the Birkenhead works he removed to the Saville Street Engineering Works in Sheffield, where in connection with the Clay Cross Co. these steam tramcars were constructed. While in Sheffield he was greatly interested in the manufacture of steel, as well as in general engineering work; and was appointed manager of a new concern started at Barrow-in-Furness, in which the late Mr. Daniel Adamson was interested. There he remained until 1887, when he became manager of the steel and ironworks department of Messrs. Palmer's Shipbuilding and Iron Co. at Jarrow-on-Tyne, where he put up several large steel-smelting furnaces and a 36-inch bar mill. In 1891 he became managing director of the Bowling Iron Co., Bradford, where he remained until his death, which took place after a brief illness on the 12th May 1895, at the age of forty-six. He became a Member of this Institution in 1892; and was also a Member of the Institution of Civil Engineers and of the Iron and Steel Institute.

John Henry Greener was born at Etherley, County Durham, on 26th June 1829. He began his career in London with his uncle, Thomas Greener, who was one of George Stephenson's principal assistants in the construction of the Stockton and Darlington, the Liverpool and Manchester, and other railways, ending with the Blackwall. It was in connection with the last that in 1843 he began to be engaged in electrical engineering in London. In 1847 he entered the service of the old Electric Telegraph Co., with which he was connected for two years; and then returned to the Blackwall Railway in 1849 to take charge of the telegraphs. In 1853 he re-joined the Electric Telegraph Co., by whom he was sent to construct the telegraph along the Norwegian Trunk Railway, which

was the first line of telegraph erected in the Scandinavian Peninsula. In 1855 he went to Denmark to construct the telegraph on the Royal Danish Railways. Soon after his return to England, he proceeded to Ireland to report on the state of the telegraph lines between Dublin and Galway, for the purpose of establishing direct communication with the Atlantic cable. At the end of 1860 he was appointed by the Secretary of State for India as telegraphic engineer to examine and report on the condition of the Turkish telegraph lines in Asia Minor, connected with Constantinople, with the view of establishing overland telegraphic communication to the Persian Gulf, and thence by cable through the Gulf towards India. This work was deemed necessary in consequence of the temporary failure of the Red Sea cable, when it was felt to be important to England to secure an alternative means of communication with India. In 1862 he returned to England in order to report personally to the India Office the result of his investigations and his views on the scheme generally. As a result of this consultation, he was despatched to Bombay as telegraph engineer to an expedition for taking soundings between Kurrachee and Fao at the head of the Persian Gulf, and for selecting landing places for a proposed cable between those points. He had previously constructed the land lines from Baghdad through Mesopotamia to Fao; and the cable having been laid successfully to Kurrachee, communication between England and India along this route was completed in January 1865. Returning to England, he was appointed inspecting engineer for telegraph stores to the India Office; and also held the same position to the Crown Agents for the Colonies. In April 1887 he resigned his position at the India Office, but his connection with the Colonial Office was maintained till his death. This took place at his residence at Herne Hill, London, on 7th April 1895, in his sixty-sixth year. He became a Member of this Institution in 1871.

Edward Cartwright Harvey was born at Londonthorpe, near Grantham, on 29th September 1866. In 1882 he commenced a term of instruction with Messrs. Hornsby and Sons, Grantham, and was subsequently employed by them as draughtsman in 1887–8, and

then went to Johannesburg. Early in 1890 he entered the drawing office of Messrs. Howard Farrar and Co., Johannesburg, and remained with them a few months. He then became engineer to the May Gold Mining Co., for whom he superintended the erection of hoisting, pumping, rock-drilling, and other machinery; and subsequently was appointed foreman engineer to the Transvaal Silver Mines, where he erected a considerable amount of machinery. He was next appointed resident engineer to the Geldenhuis Estate and Gold Mining Co., where he erected an 80-stamp battery, and a large set of pumping, hoisting, and air-compressing machinery. In the early part of 1893 he left for England. Returning to Johannesburg he took charge of a contract for the Geldenhuis Deep Mining Co.; and while carrying out this work met with an accident which caused his death. A winding-engine drum slipped from the slings whilst being lifted from the truck, and fell on his foot; from exhaustion and from shock after amputation he died on 13th October 1894, at the age of twenty-eight. He became a Member of this Institution in 1892.

John Wild was born at Moston near Manchester on 22nd April 1862. He was early at work in his father's smithy, after which he obtained a situation with a firm of colliery proprietors in the district, and was appointed foreman in his department at the age of nineteen. In 1883 he commenced business in colliery engineering for himself at Chadderton, and designed a hauling engine with special valve-gear and balanced valves, now well known in all colliery districts. After a few years the works became too small; and in 1889, in order to meet the increasing demands for his special work, the commodious premises of the Falcon Iron Works in Oldham were secured. These have since been considerably extended to meet the growing demand for hauling and winding engines, air-compressors, and colliery engineering work in general. He was managing director, and had full control of the business up to the time of his death, which took place at Oldham on 6th March 1895, in his thirty-third year. He became a Member of this Institution in 1890.

Robert Henry Wood was born in Leeds on 25th October 1851. His grandfather was the founder of the Larchfield Works, Hunslet, well known for many years as Robert Wood and Sons, at which were built a great number of the early stationary engines then used in the neighbourhood of Leeds; and they are said to have been the first in the district to make engines compound on the McNaught system, many of which, compounded by them, are still working. On the death of his grandfather, Robert Wood, the business was carried on by his father, William Stewart Wood, and his uncles; and at sixteen years of age he commenced practical work there. For some time he was in the drawing office of Messrs. Kitson and Co., Leeds, and afterwards in the workshops and drawing office of his father's firm. From 1874 to 1880 he was in the drawing office of Messrs. Tannett, Walker and Co., and Messrs. Joseph Whitham and Sons, Leeds; and from 1880 to 1888 he was practical outdoor manager to Messrs. Tannett, Walker and Co., during which time he superintended the erection of important hydraulic and other machinery. For a year he was in Spain at the Rio Tinto mines, superintending the erection and starting of ore-crushing machinery; and on his return to England he superintended the erection of a large amount of hydraulic and other machinery in London, Aberdeen, Cardiff, Greenock, Hartlepool, Grimsby, and Middlesbrough. Being a first-rate draughtsman and a good mechanic, he originated many improvements in the details of various machines; and early made experiments in electricity and in pumping. Having been considerably out of health for some time previously, he died at Headingley, Leeds, on 12th June 1895, in his forty-fourth year. He became a Member of this Institution in 1885.

INDEX.

1895.

Parts 1–2.

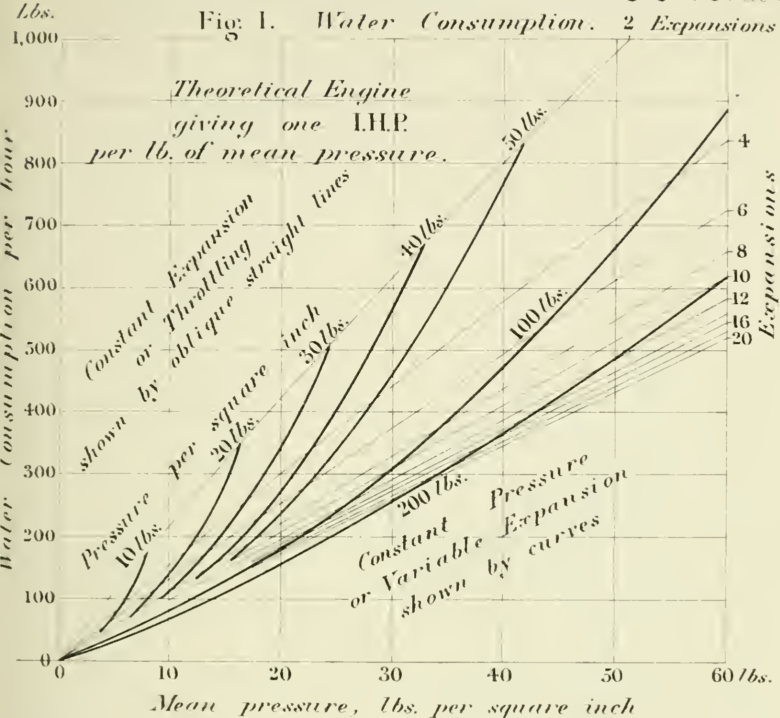


Fig. 1. Water Consumption. 2 Expansions
Theoretical Engine
giving one I.H.P.
per lb. of mean pressure.
Constant Expansion
or Throttling
shown by oblique straight lines
Pressure per square inch
10 lbs.
20 lbs.
30 lbs.
40 lbs.
50 lbs.
100 lbs.
200 lbs.
Constant Pressure
or Variable Expansion
shown by curves
Expansions
4
6
8
10
12
16
20
Lbs.
1,000
900
800
700
600
500
400
300
200
100
0
Water Consumption per hour
0
10
20
30
40
50
60 lbs.
Mean pressure, lbs. per square inch

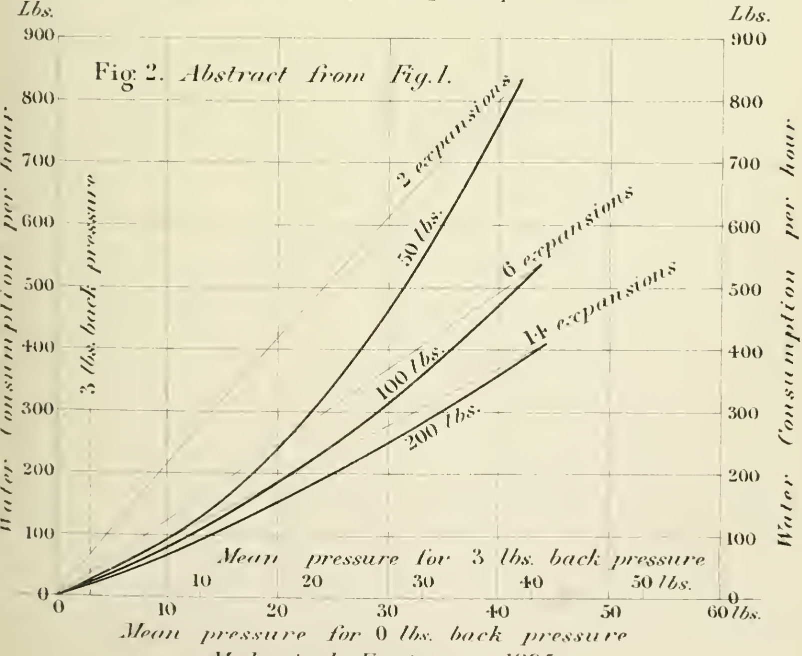
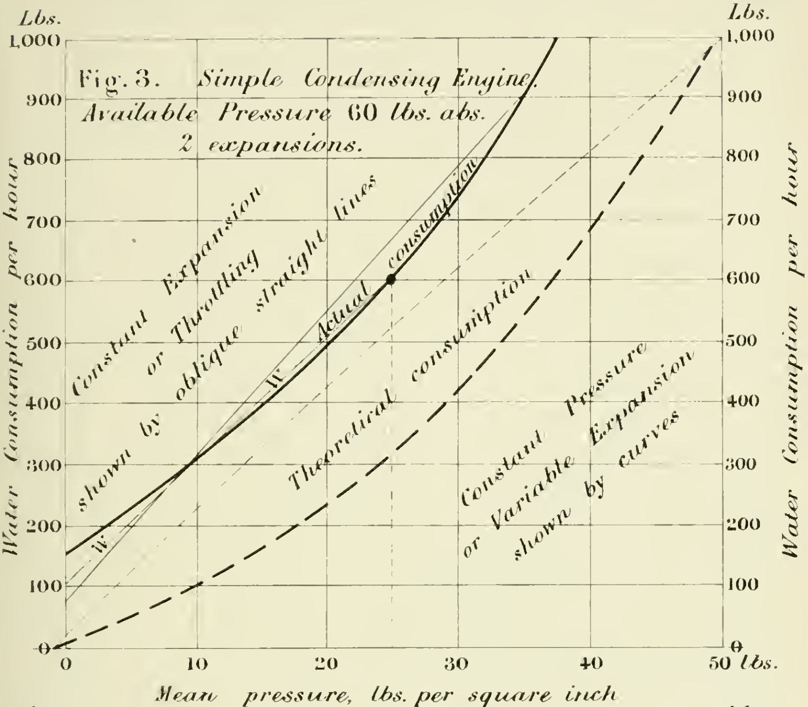


Fig. 2. Abstract from Fig. 1.
2 expansions
50 lbs.
6 expansions
100 lbs.
14 expansions
200 lbs.
3 lbs. back pressure
Lbs.
900
800
700
600
500
400
300
200
100
0
Water Consumption per hour
Mean pressure for 3 lbs. back pressure
10
20
30
40
50 lbs.
0
10
20
30
40
50
60 lbs.
Mean pressure for 0 lbs. back pressure

THROTTLING AND VARIABLE EXPANSION. *Plate 21.*



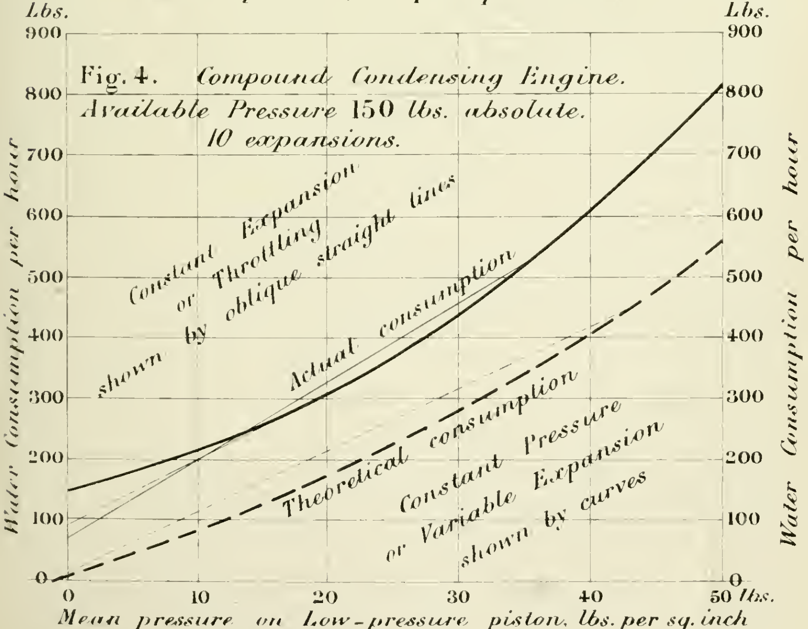


Fig. 5.

Compound Condensing Engine.
Available Pressure 150 lbs. absolute.

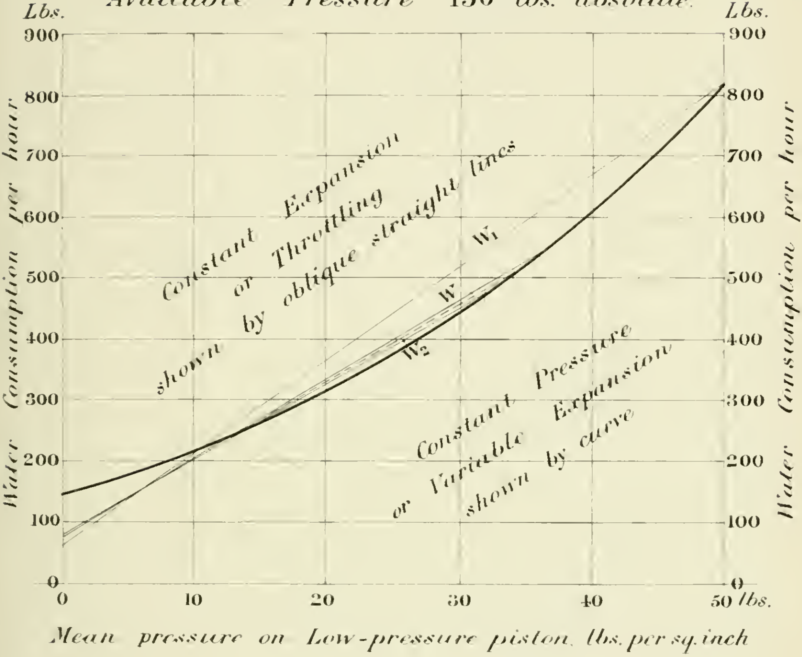
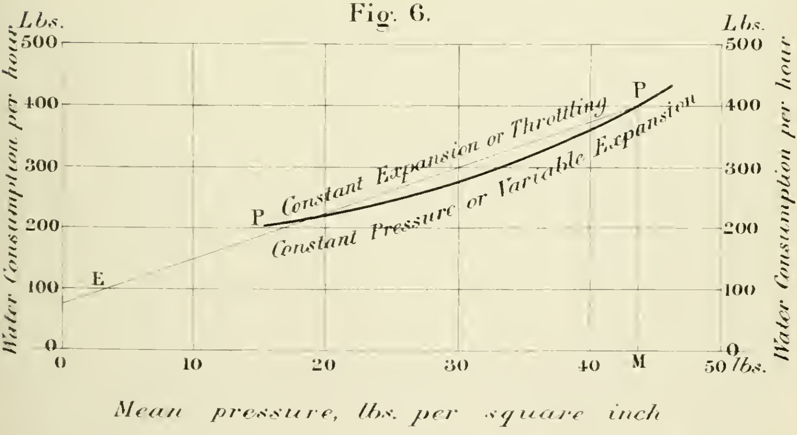
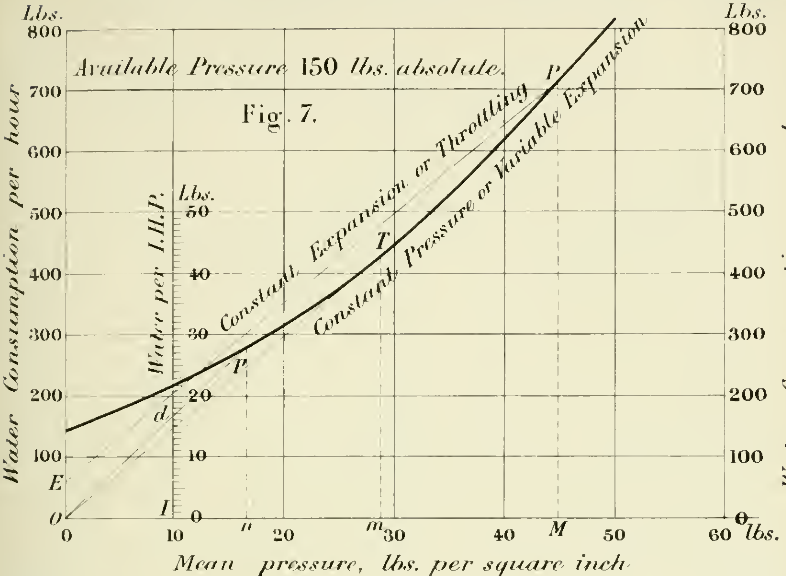


Fig. 6.




Available Pressure 150 lbs. absolute.
Fig. 7.
Constant Expansion or Throttling
Constant Pressure or Variable Expansion
Water Consumption per hour
Water per I.H.P.
Lbs.
Mean pressure, lbs. per square inch

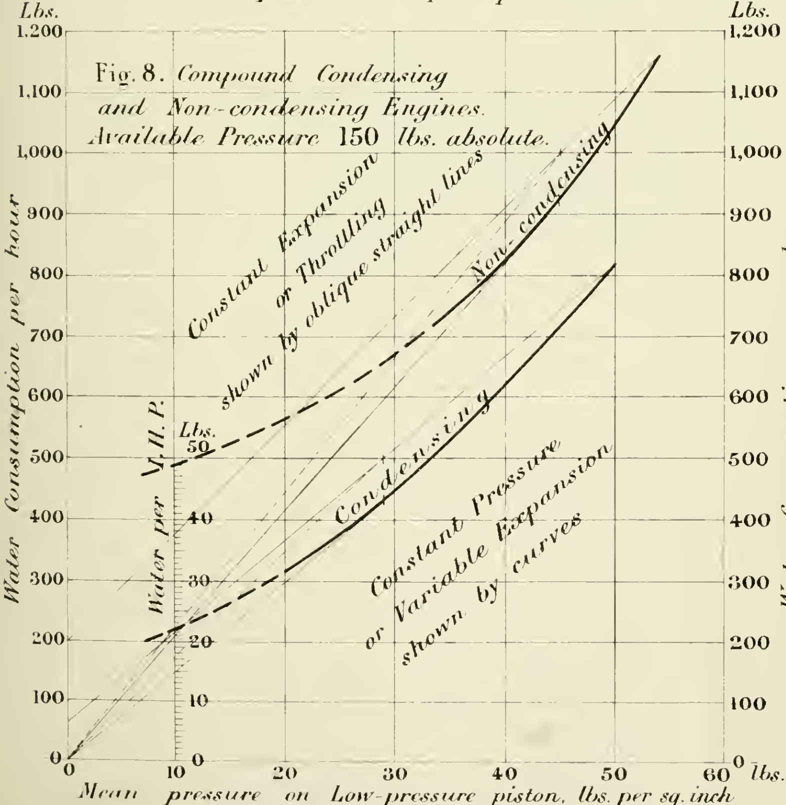


Fig. 8. Compound Condensing and Non-condensing Engines.
Available Pressure 150 lbs. absolute.
Constant Expansion or Throttling shown by oblique straight lines
Non-condensing
Condensing
Constant Pressure or Variable Expansion shown by curves
Water Consumption per hour
Water per I.H.P.
Lbs.
Mean pressure on Low-pressure piston, lbs. per sq. inch

THROTTLING AND VARIABLE EXPANSION.

Compound Receiver Engine.

Effect of Sudden Increase in Load.

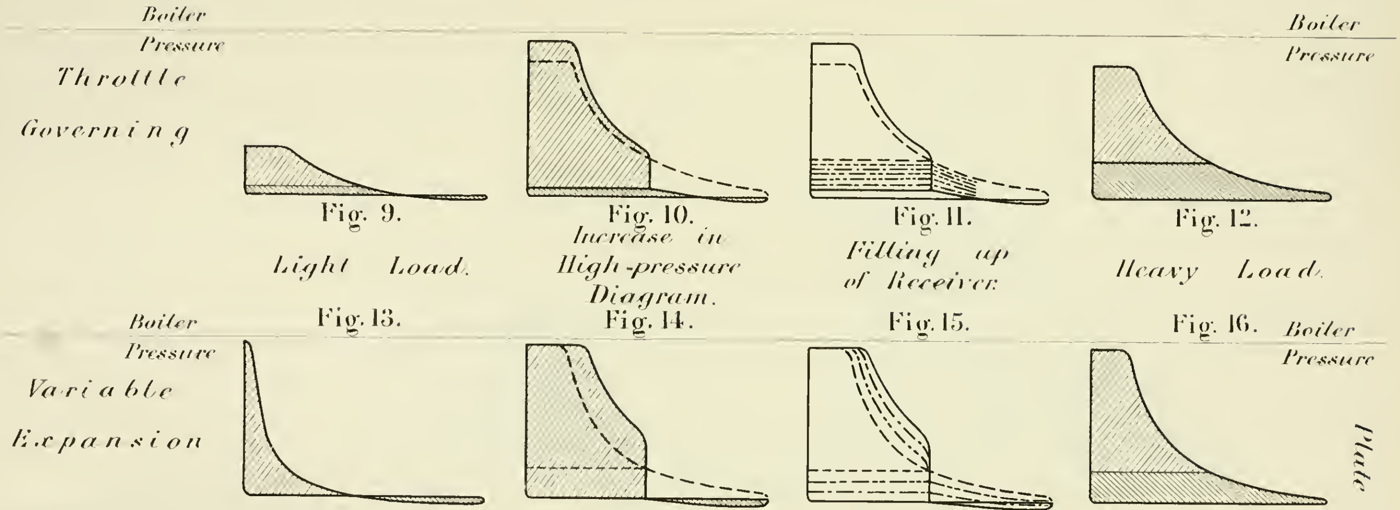


Plate 24.

THROTTLING AND VARIABLE EXPANSION.

Fig. 17. *Load-Curve at Kensington Court Electric-Light Station, 2 Dec. 1890.*
Condensing Engines with Throttle Governing.
Cut-off arranged for 34 lbs. Mean Pressure with 150 lbs. absolute.
Each unit starts ten minutes before it is required.

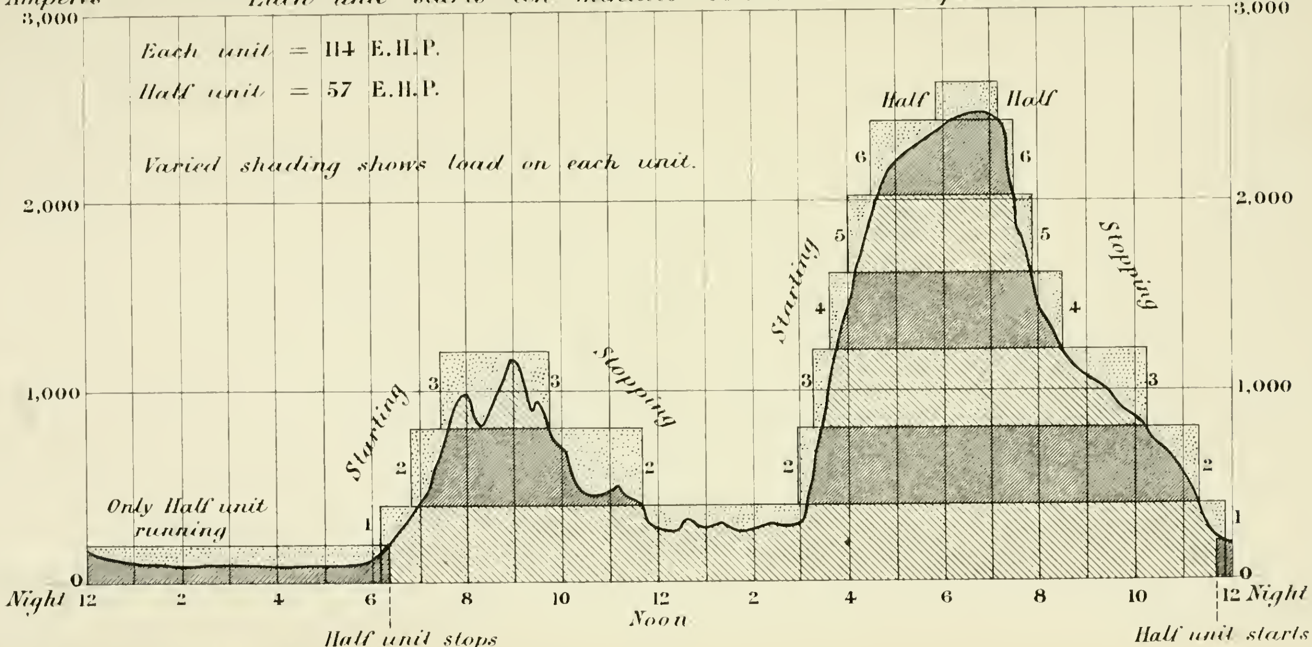


Plate 25.

Fig. 18. *Load-Curve at Kensington Court Electric-Light Station, 2 Dec. 1890.*
Condensing Engines with Variable Expansion.
Available Pressure 150 lbs. absolute.
Each unit starts five minutes before it is required.

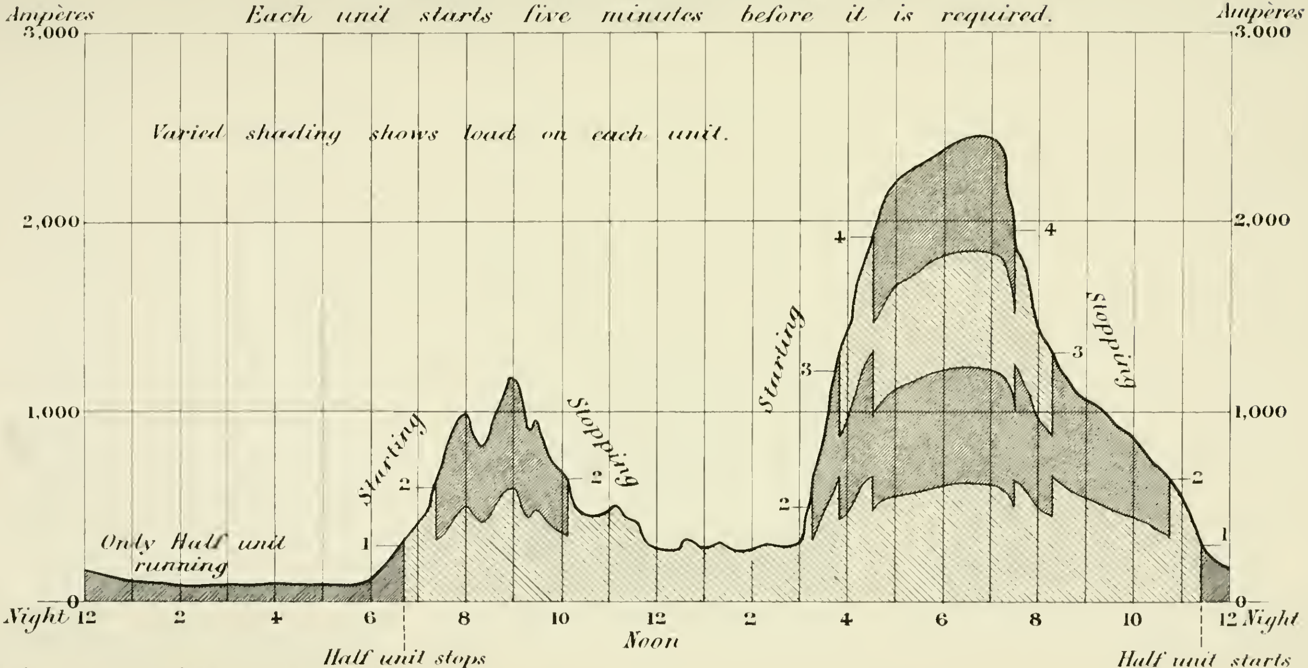
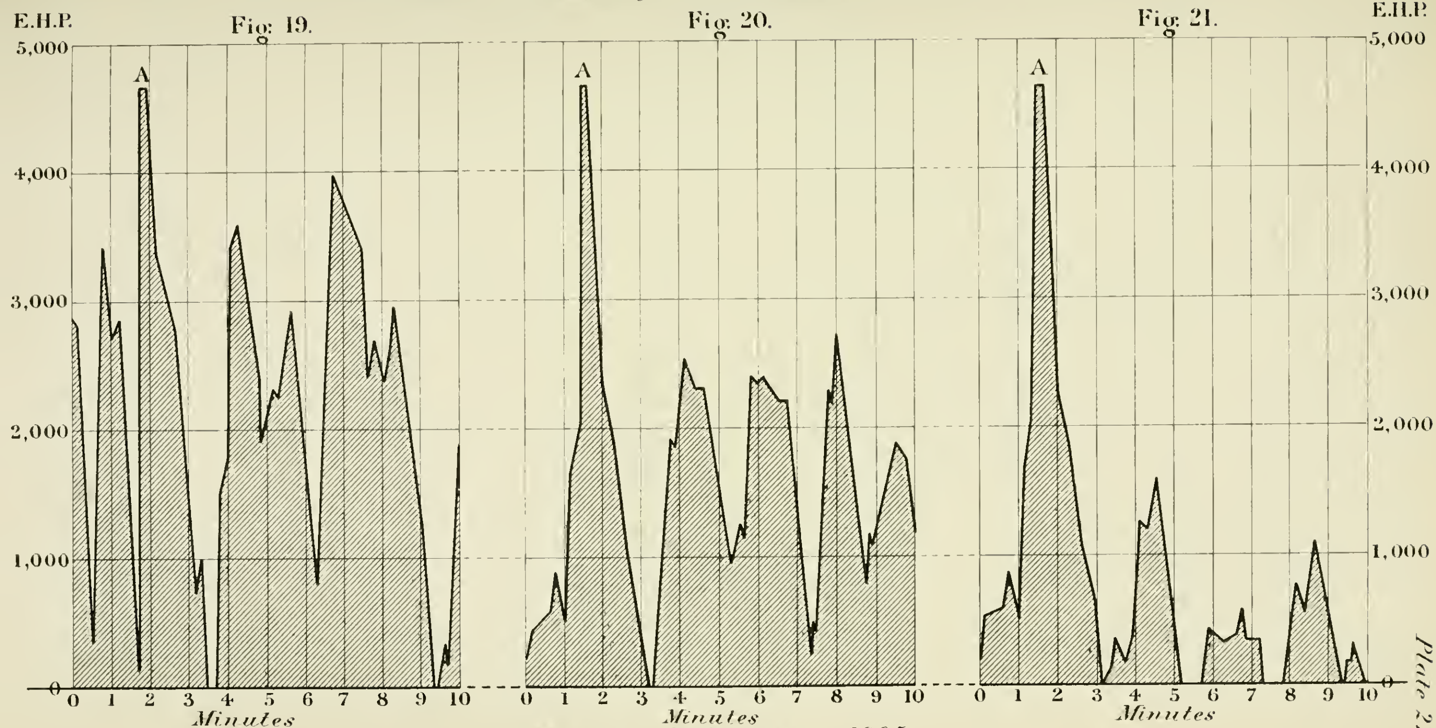


Plate 26.

THROTTLING AND VARIABLE EXPANSION.

Electric Railway. Typical Load-Curves.



Mechanical Engineers 1895.

Plate 27.

Fig. 22. *Load-Curve for a Single Electric-Light Engine.*

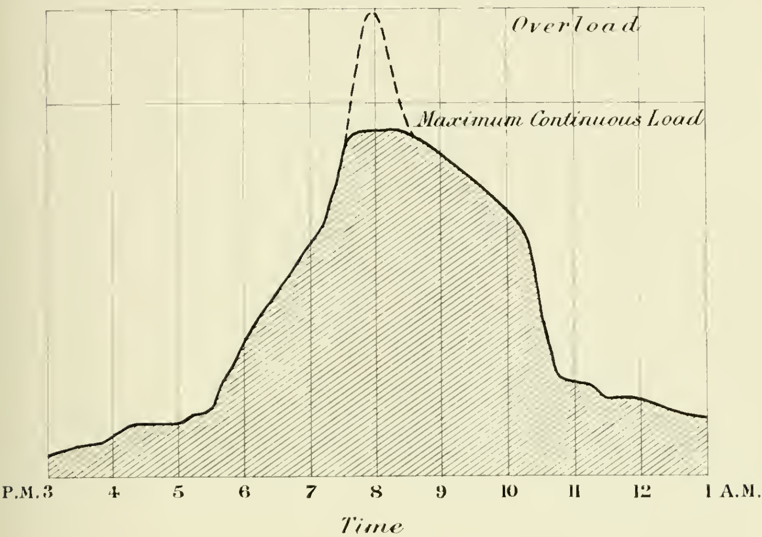
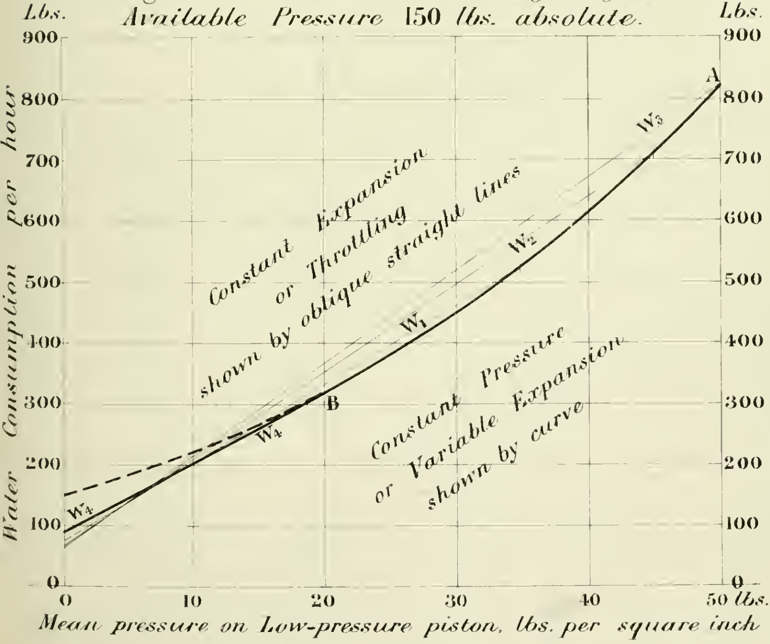


Fig. 23. *Compound Condensing Engine. Available Pressure 150 lbs. absolute.*



Mechanical Engineers 1895.

Fig. 24. *Compound Condensing Engine giving 1,000 Indicated Horse-Power at 34 lbs. Mean Pressure.*

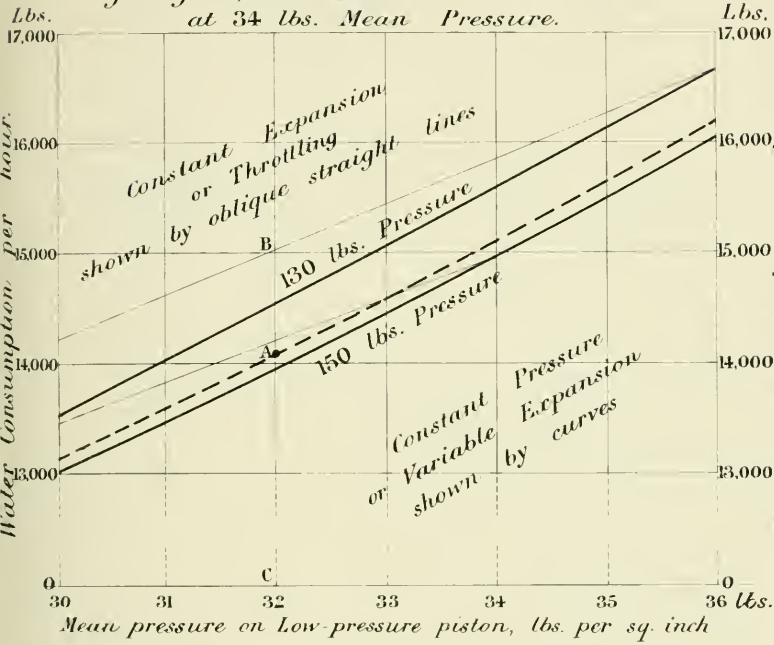


Fig. 25. *Throttling Engine. Comparison of Consumptions with Varying Boiler-Pressure and No Throttling, and with Constant Boiler-Pressure and Throttling.*

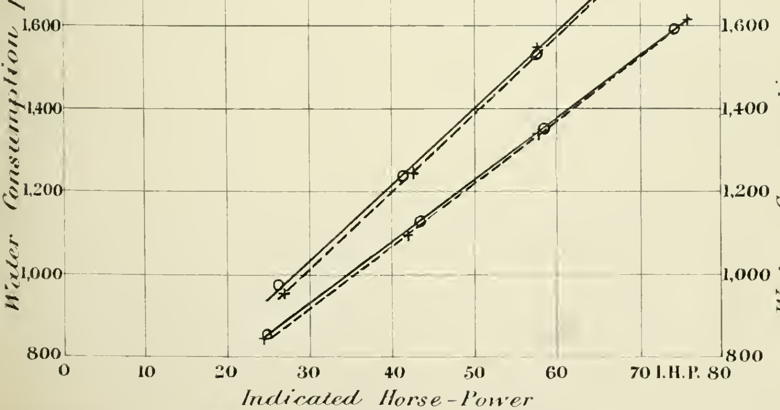
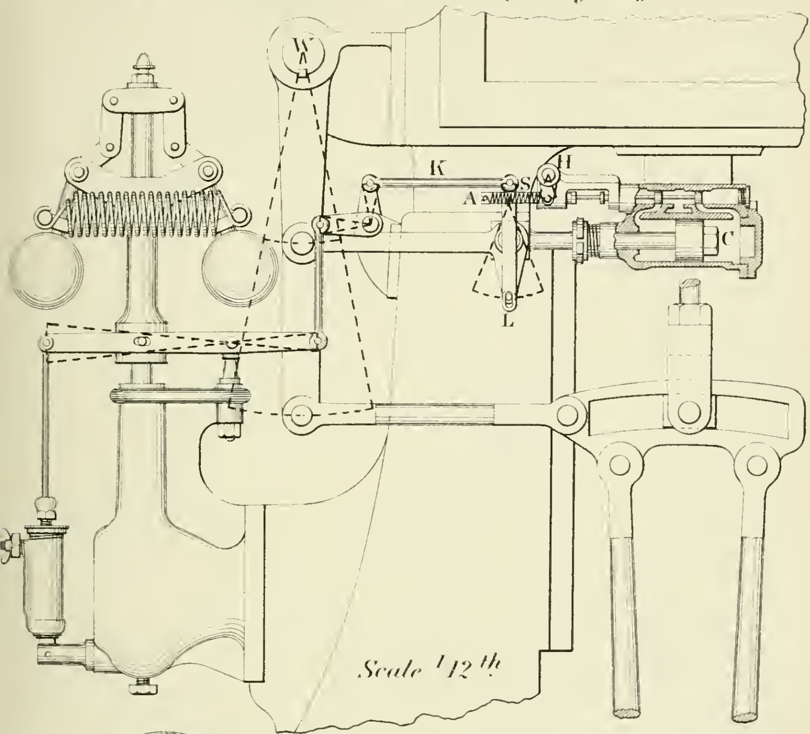


Fig: 26. *Variable-Expansion Gear on each cylinder of Triple-Expansion Electric-Lighting Engines.*



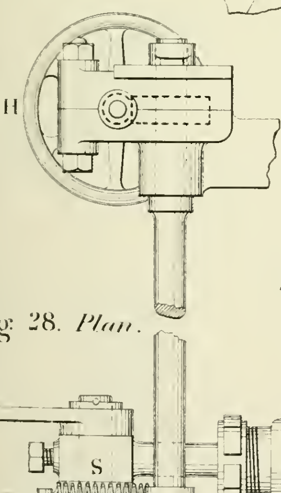
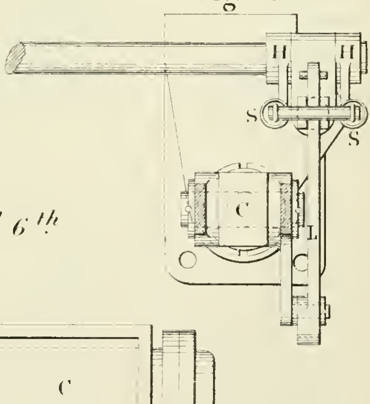
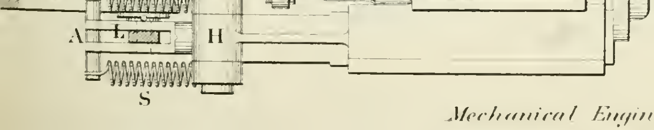


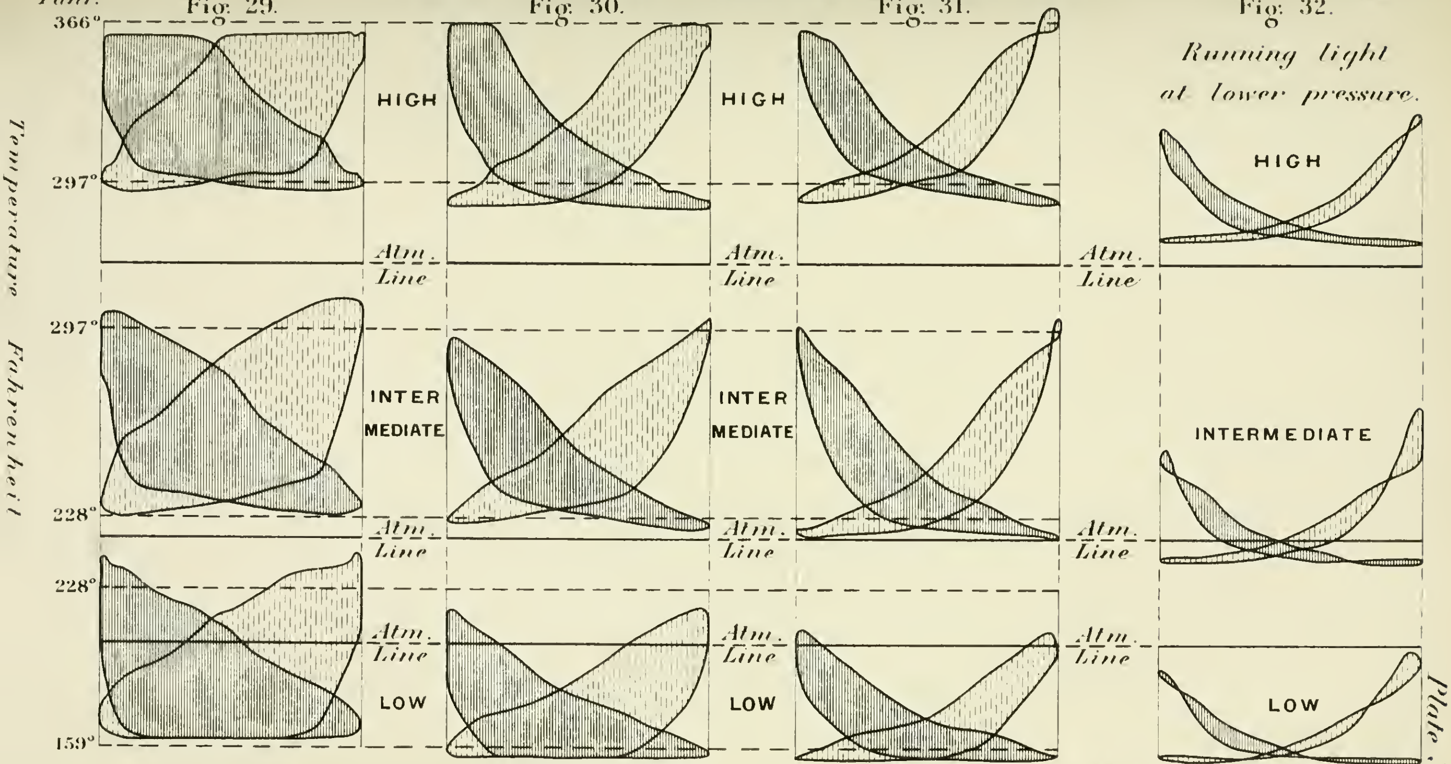
Fig: 27.



Scale 1/6th

Fig: 28. *Plan.*





317 I.H.P. 181 I.H.P. 124 I.H.P.

Automatic Expansion Governor.

Fig. 33.
Full Break.

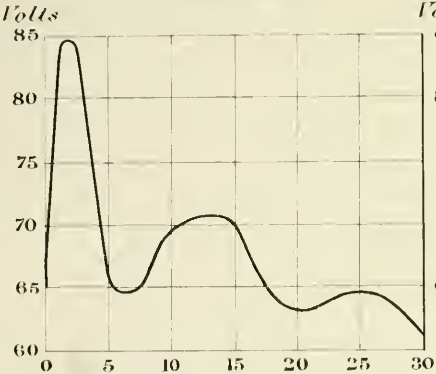


Fig. 34.
Small Break.

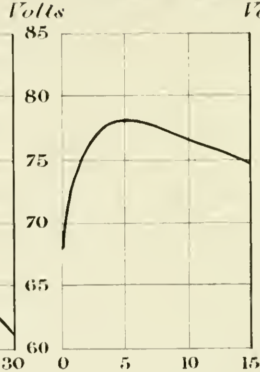


Fig. 35.
Full Break.

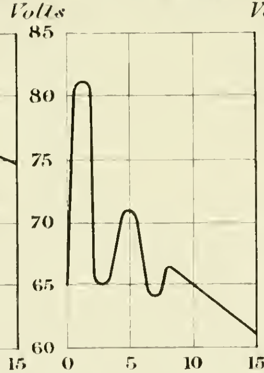


Fig. 36.
Small Break.

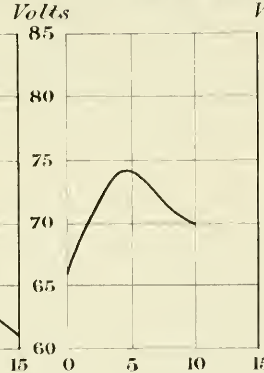
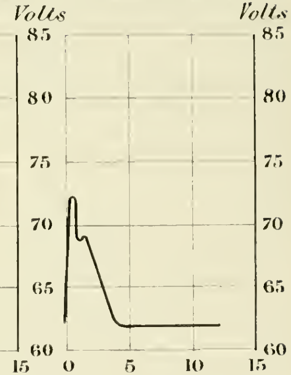


Fig. 37.
Full Break.



Time in Seconds

Mechanical Engineers 1895.

Plate 32.

Water Consumption in Electric-Lighting Engines.

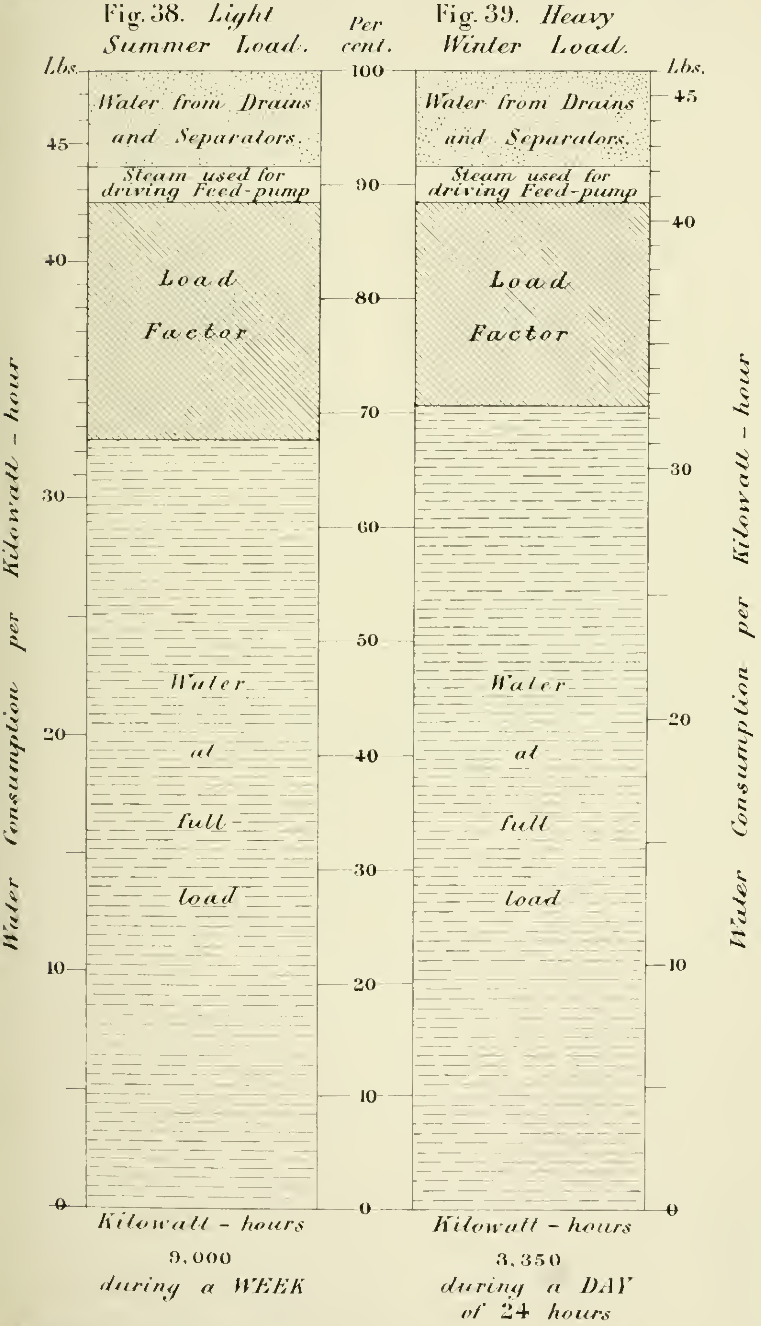


Fig. 40.

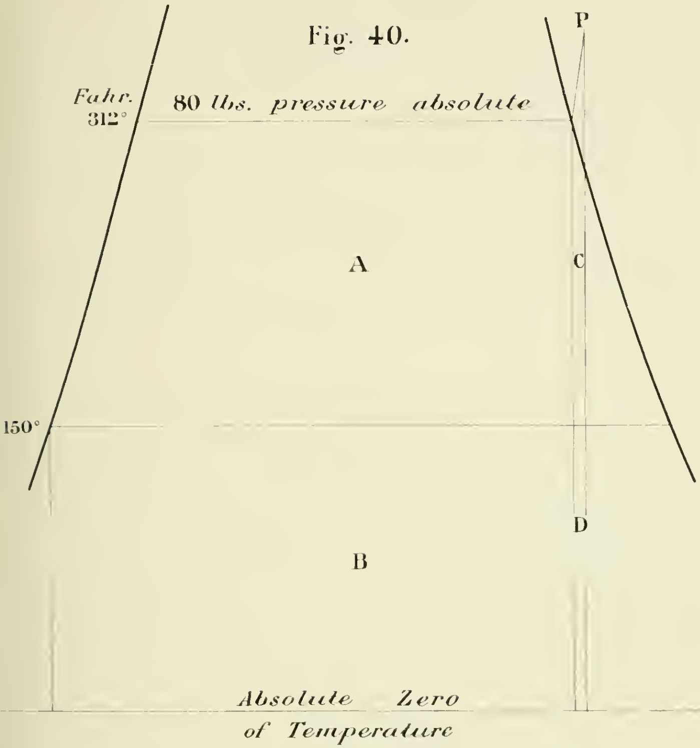


Fig. 41.

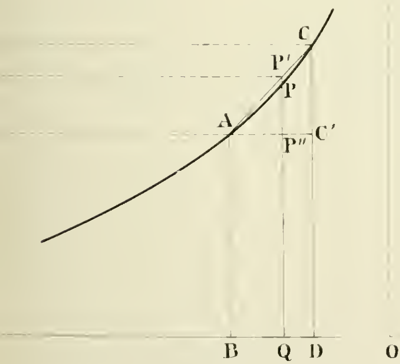
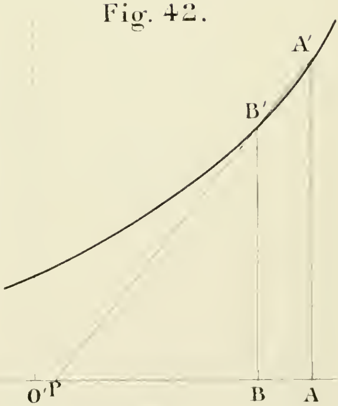


Fig. 42.



THROTTLING AND VARIABLE EXPANSION. *Plate 35.*

Indicator Diagrams from
Double-Cylinder Rolling-Mill Engine
controlled by Throttle-Valve Governor.

Boiler pressure 85 lbs. per sq. inch. Revolutions 92 per minute.

Fig. 43. *Engine running empty.*

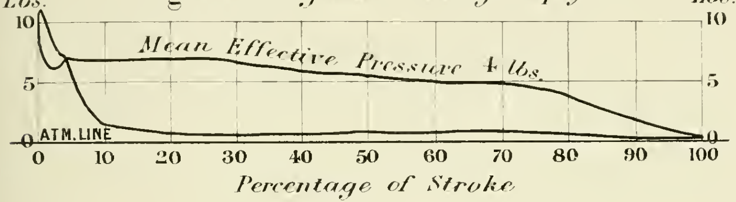


Fig. 44. *Roughing Rolls,*
rolling spring-steel billets 5 × 3 inches
out of blooms 8 inches square.

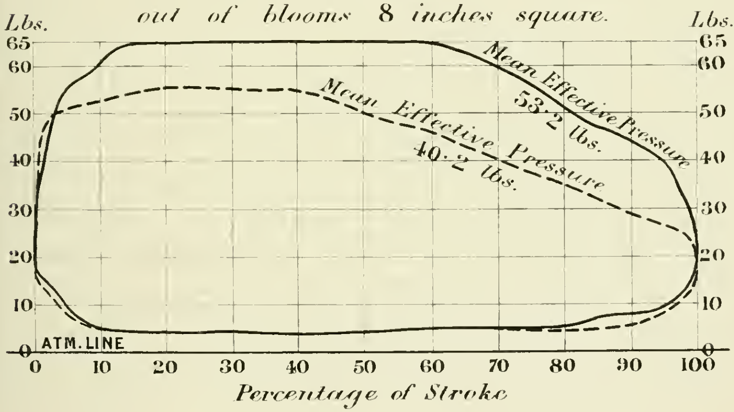
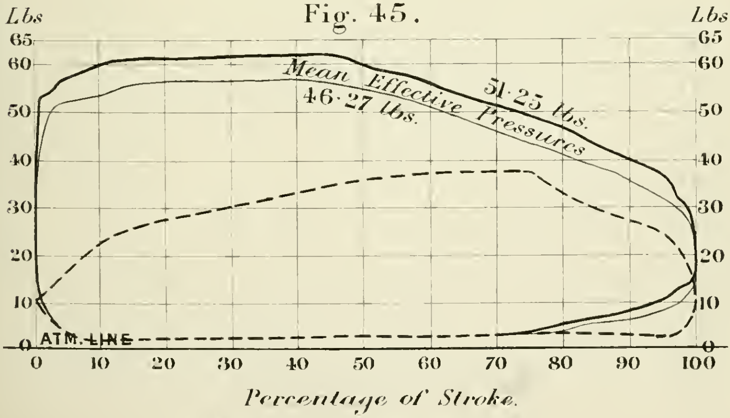


Fig. 45.



Pressure, lbs. per square inch above atmosphere

Mechanical Engineers 1895.

Fig: 46. 1,000 *I. H. P.*

Variation in Speed

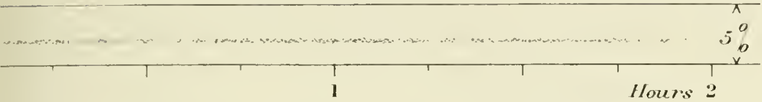


Fig: 47. *Same engine as Fig. 46.*

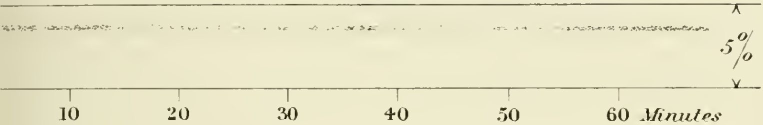


Fig: 48. *Same engine as Fig. 46.*

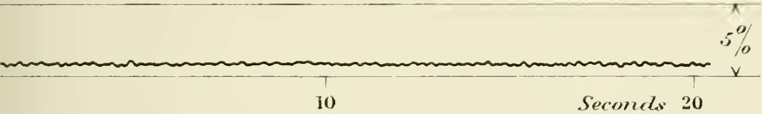


Fig: 49. 200 *I. H. P.* 350 *revs. per min.*

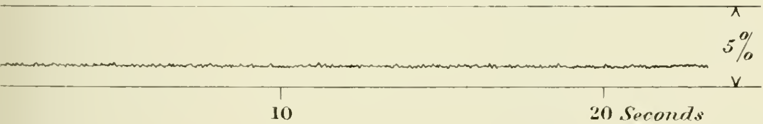


Fig: 50. 400 *I. H. P.*

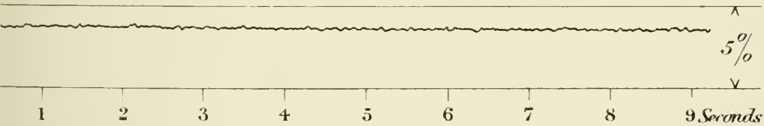


Fig: 51. *Cut-off* 24 *I. H. P.* 140 *revs. per min.*

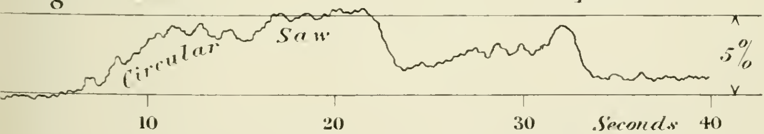


Fig: 52. *Throttle.* 60 *I. H. P.* 400 *revs. per min.*

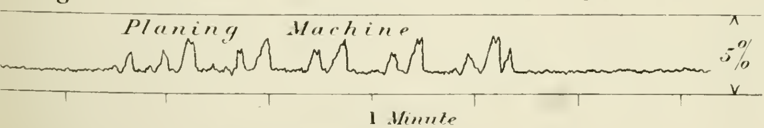
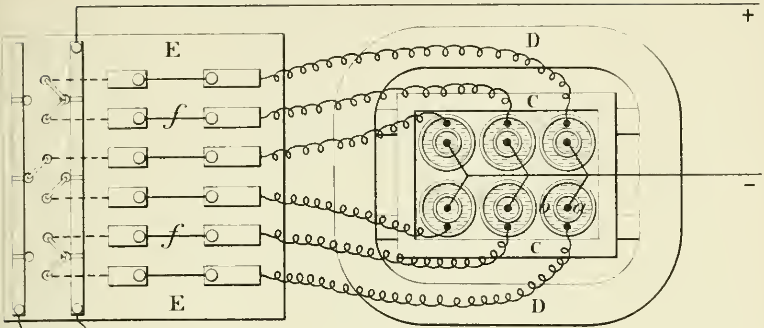
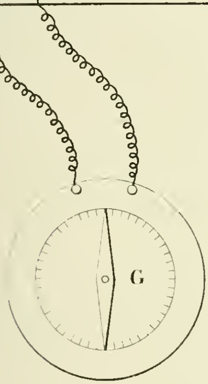


Fig. 1. *Molecular Porosity.*





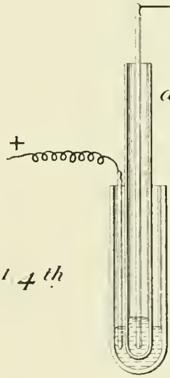


Fig. 2.
Elevation of Glass Cell.

Scale 1/4th.

Fig. 4. *Recording Pyrometer.*

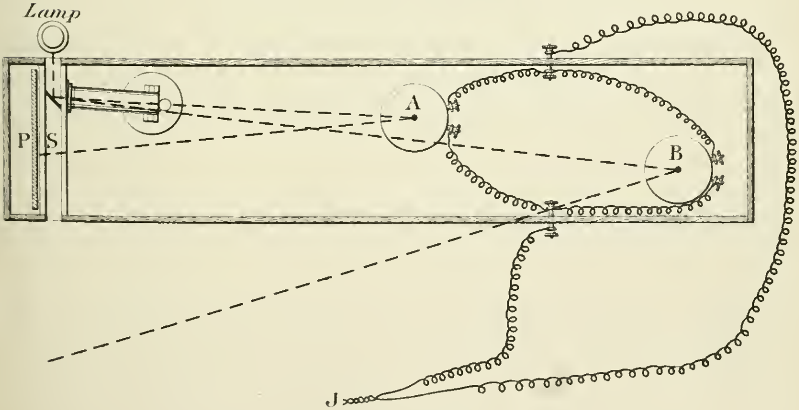


Fig. 5. *Furnace.*

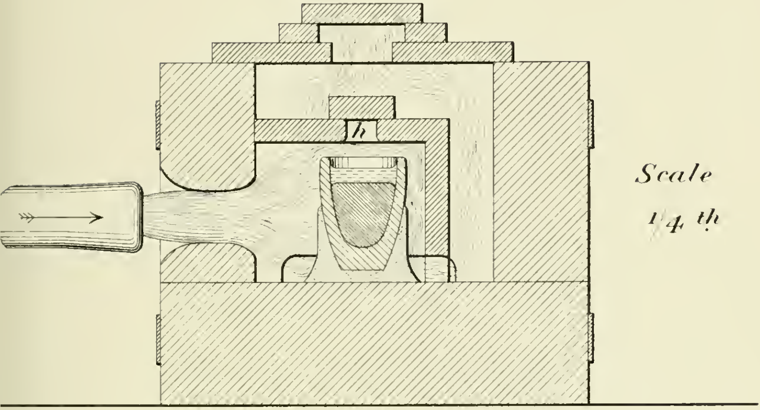


Fig. 6. *Cooling Curve of Electro-Iron.*

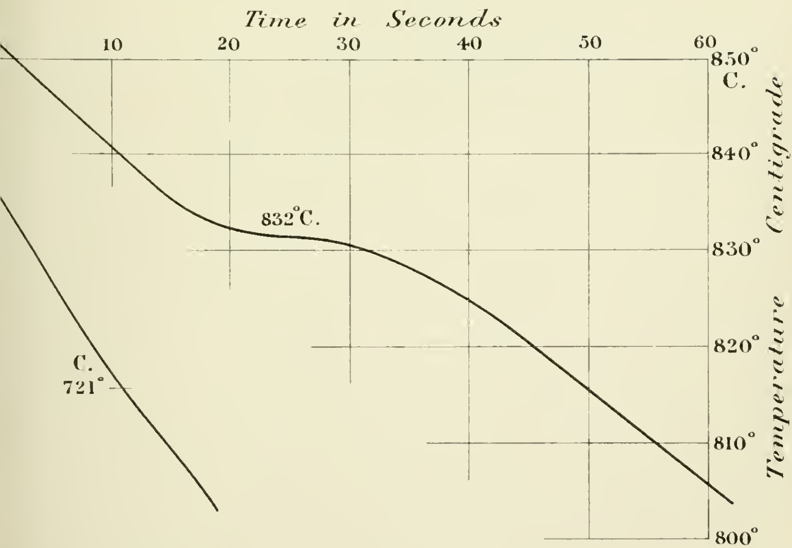


Fig: 7. *Cooling Curves of Gold, Bismuth, and Tin.*

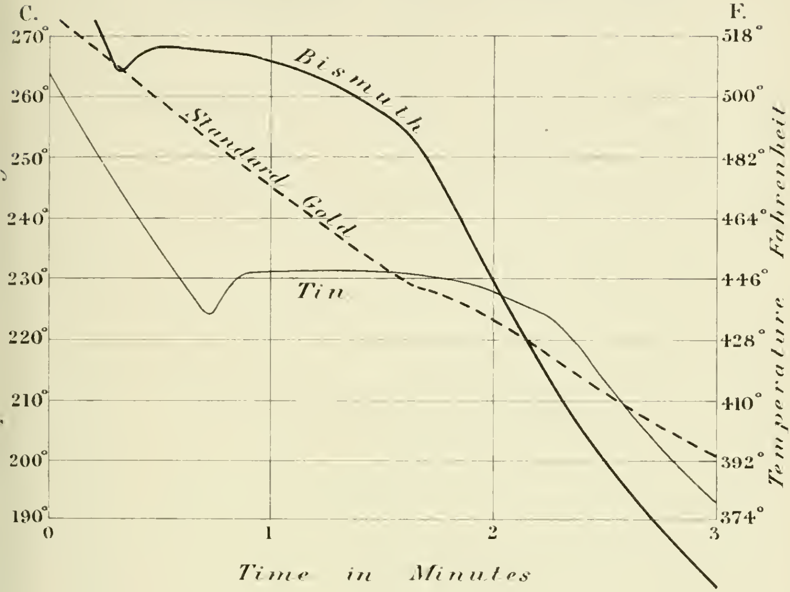


Fig: 8. *Cooling Curve of Aluminium-Copper Alloy.*

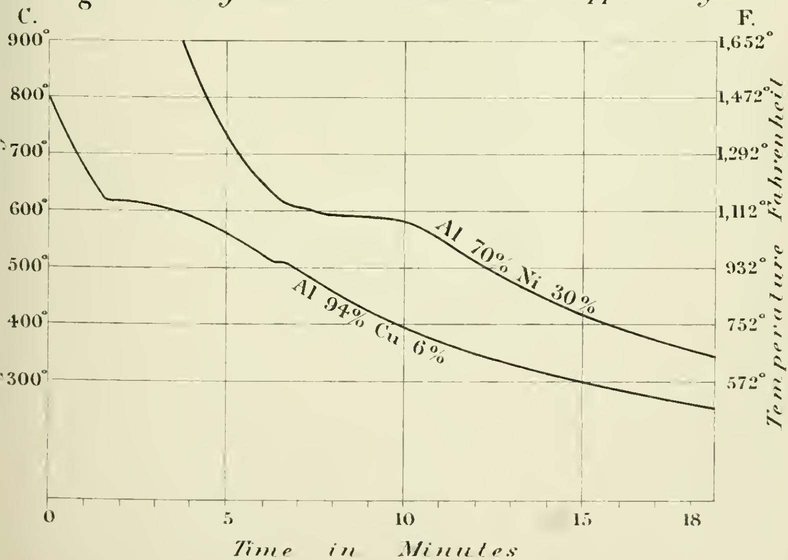


Fig: 9. *Cooling Curves of Iron-Aluminium Alloys.*

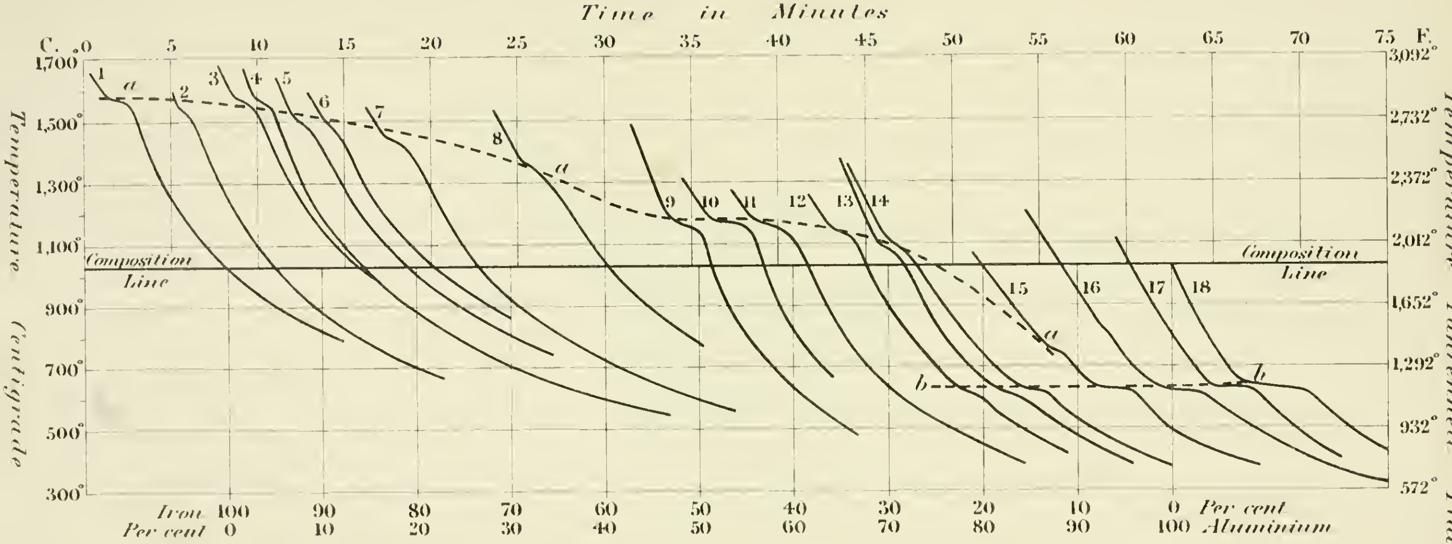
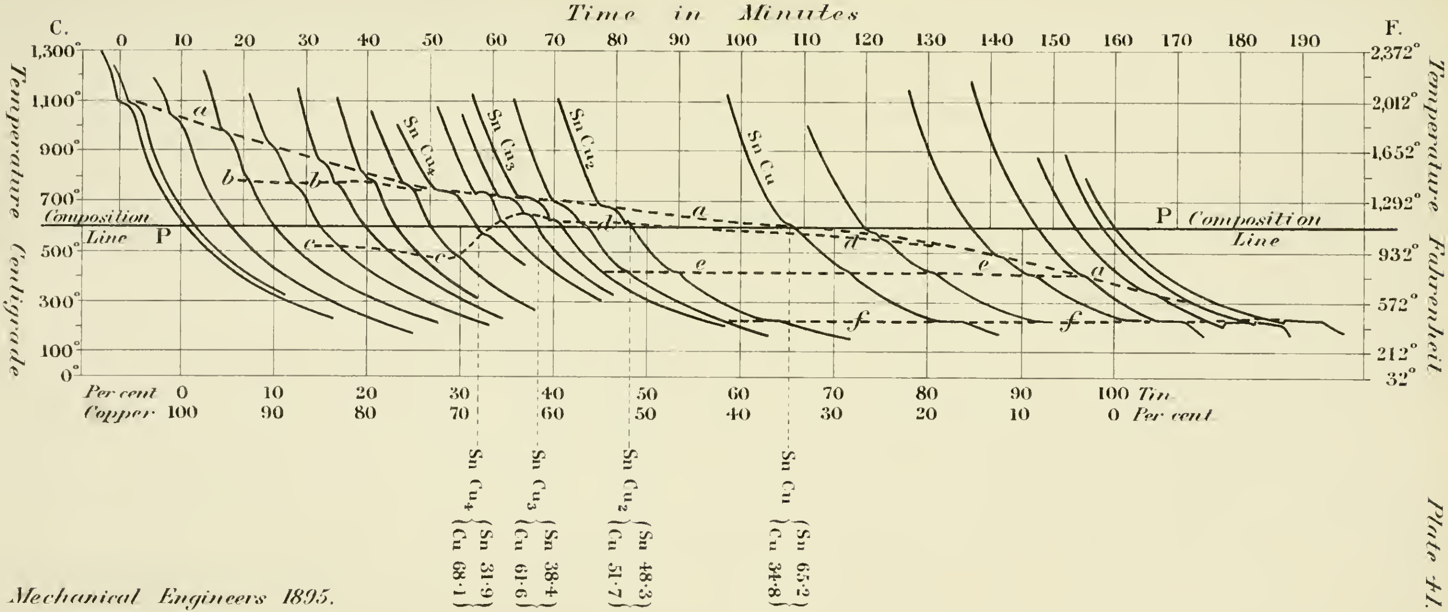


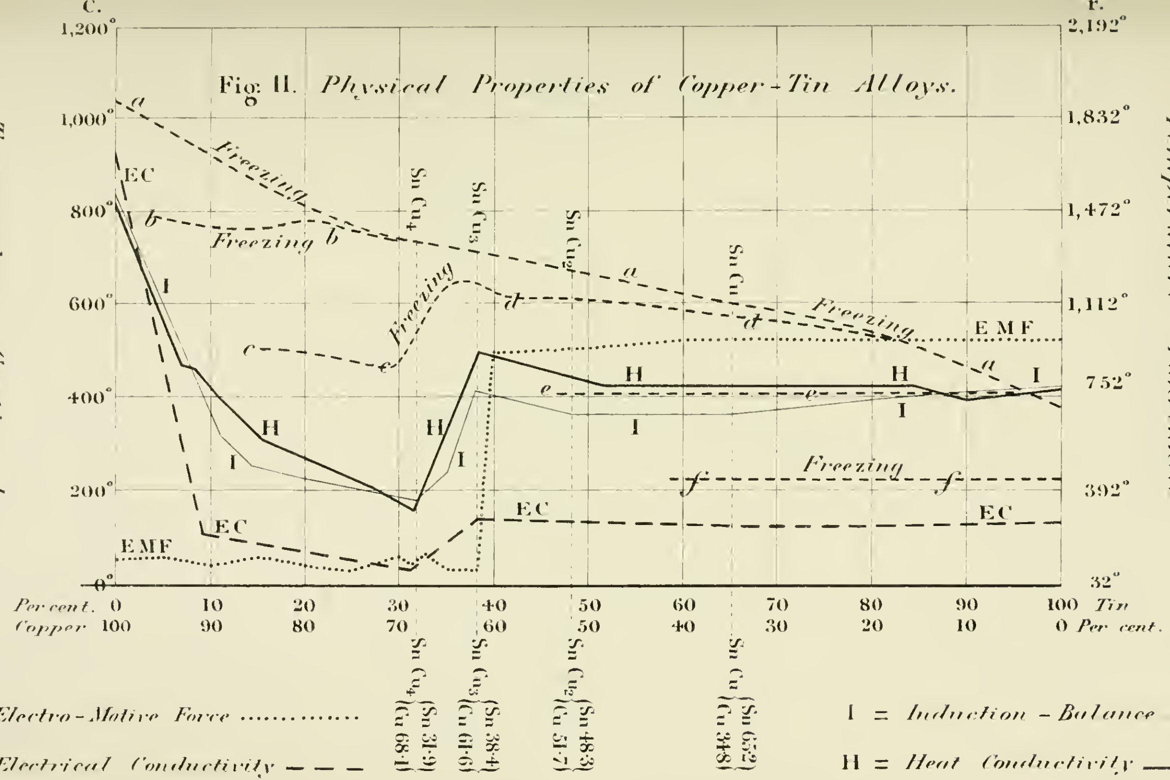
Fig. 10. *Cooling Curves of Copper - Tin Alloys.*



Mechanical Engineers 1895.

Plate 41.

Fig. 11. *Physical Properties of Copper-Tin Alloys.*



EMF = *Electro-Motive Force* ....

EC = *Electrical Conductivity* — — —

I = *Induction - Balance* ————

H = *Heat Conductivity* ————

Fig. 12. *Tensile Strength and Elongation of Copper - Tin Alloys.*

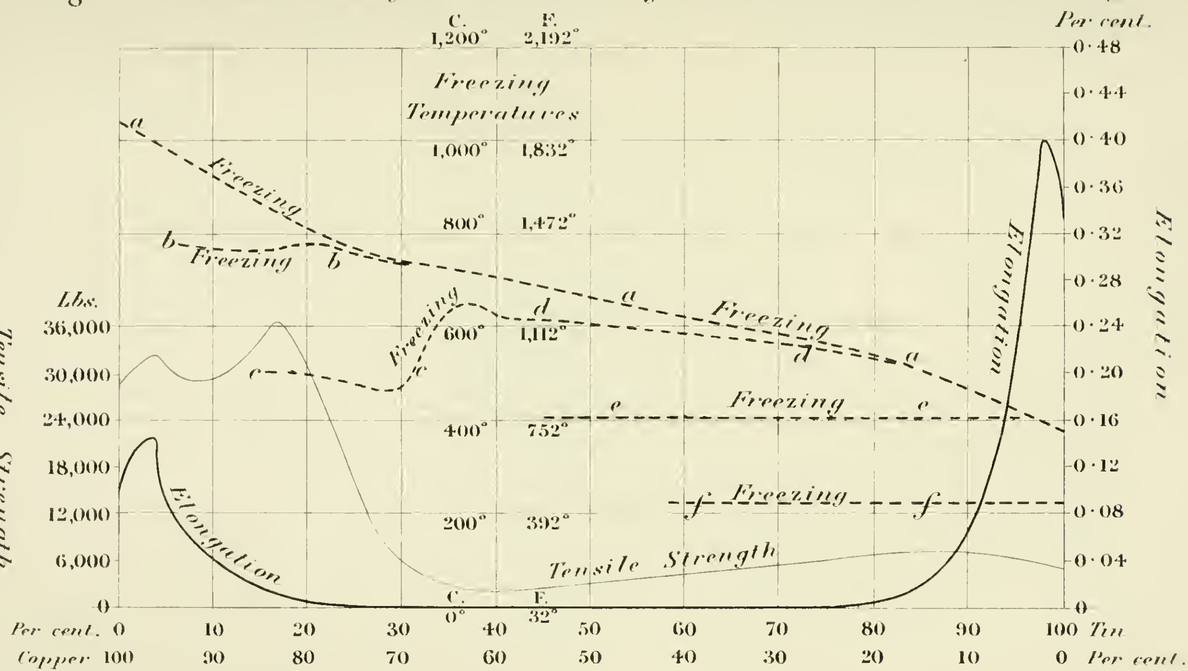


Fig. 13. *Crucible.*

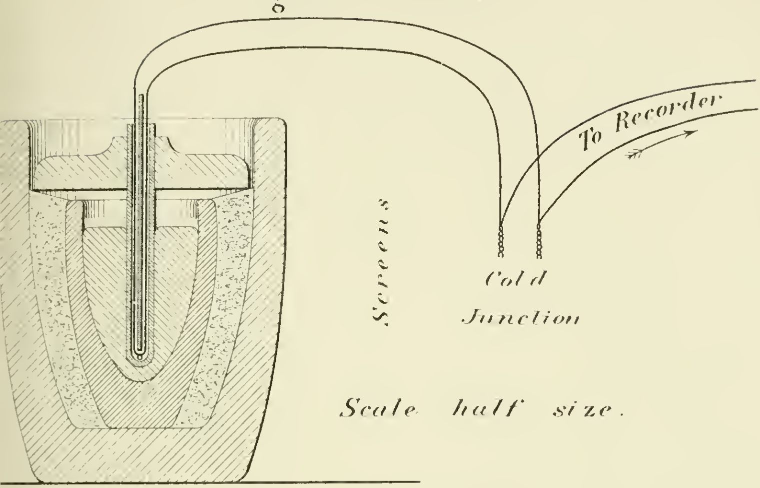
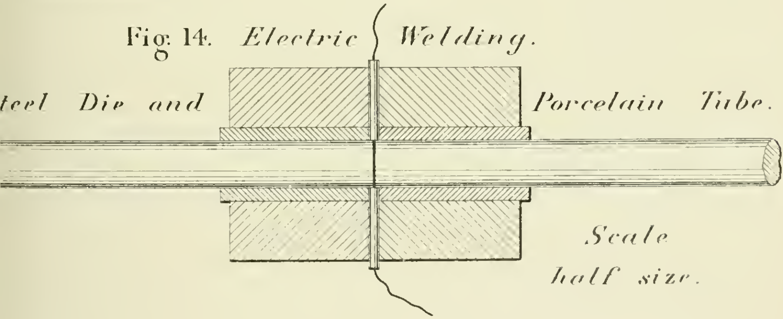


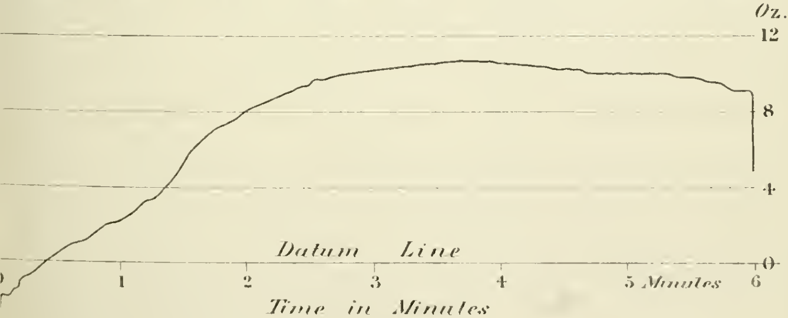
Fig. 14. *Electric Welding.*

teel Die and Porcelain Tube.

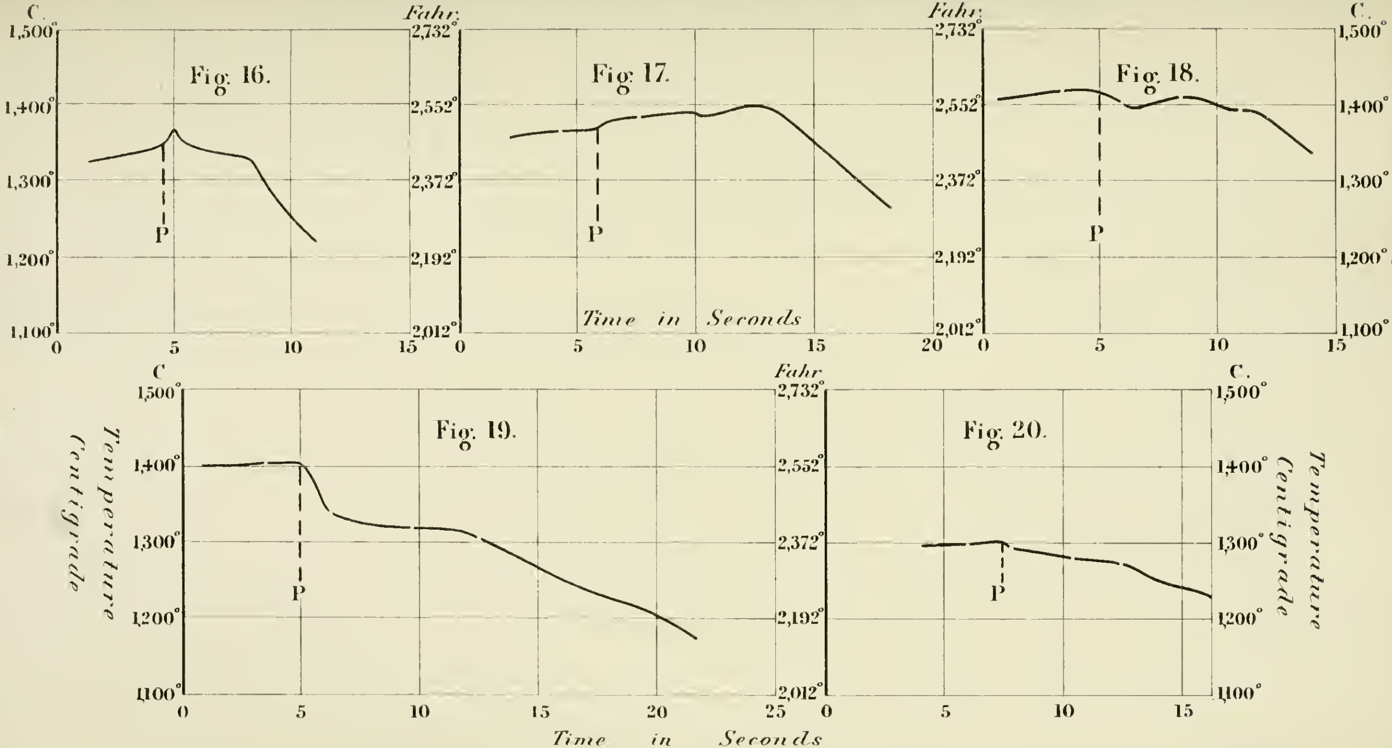


g. 15. *Curve showing Expansion and Contraction of Grey Cast-Iron in passing from the solid to the liquid state.*

Experiment with 4-inch ball weighing 132 ounces.

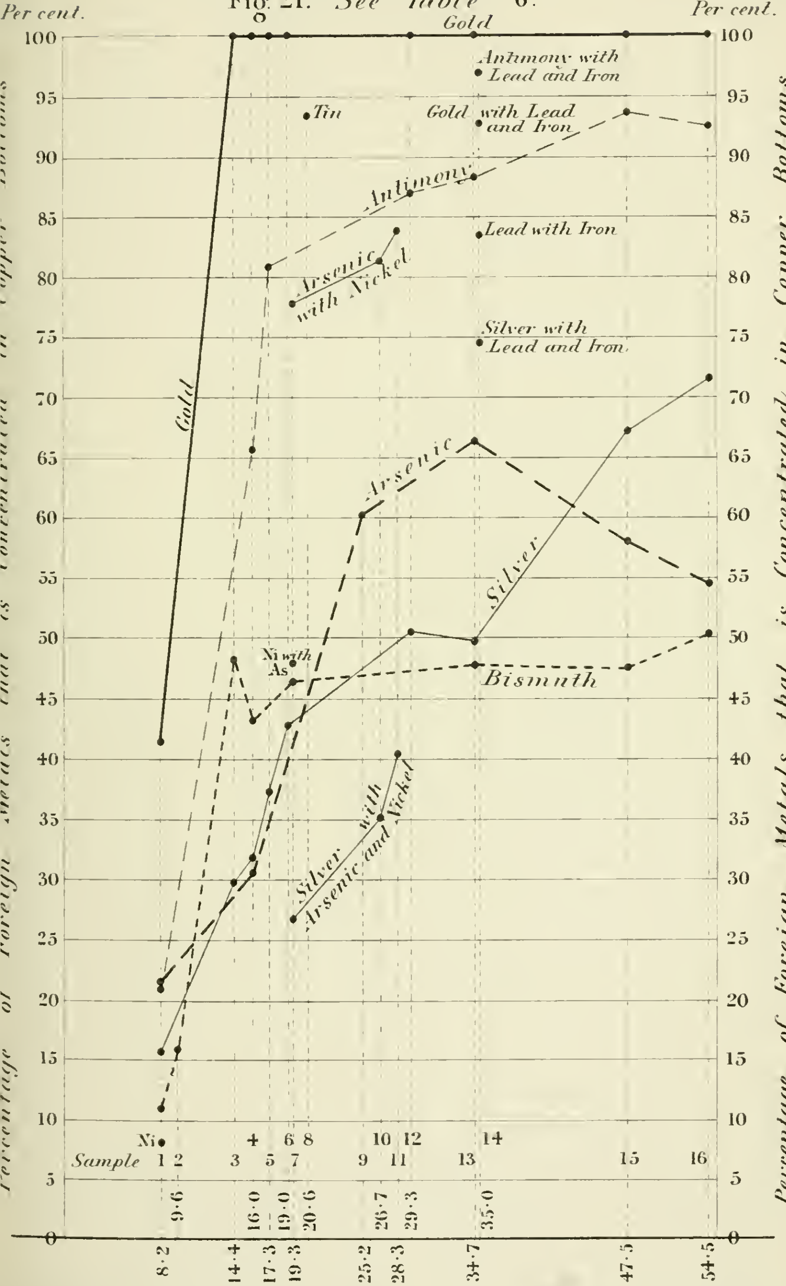


Fall of Temperature in Welding Wrought-Iron.



BEST SELECTED COPPER. *Plate 46.*

Fig. 21. *See Table 6.*

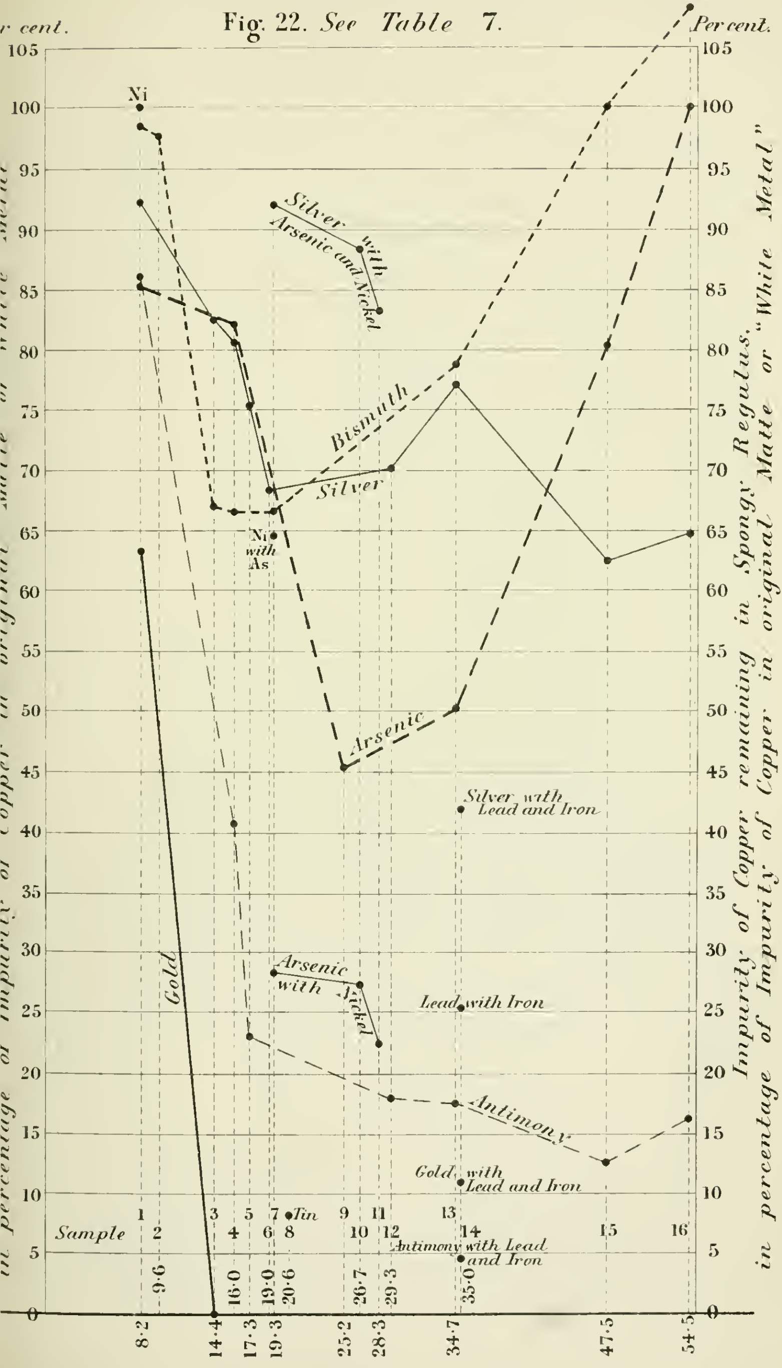


Percentages of Total Copper that are separated in Bottoms.

Mechanical Engineers 1895.

BEST SELECTED COPPER. *Plate 47.*

Fig. 22. *See Table 7.*



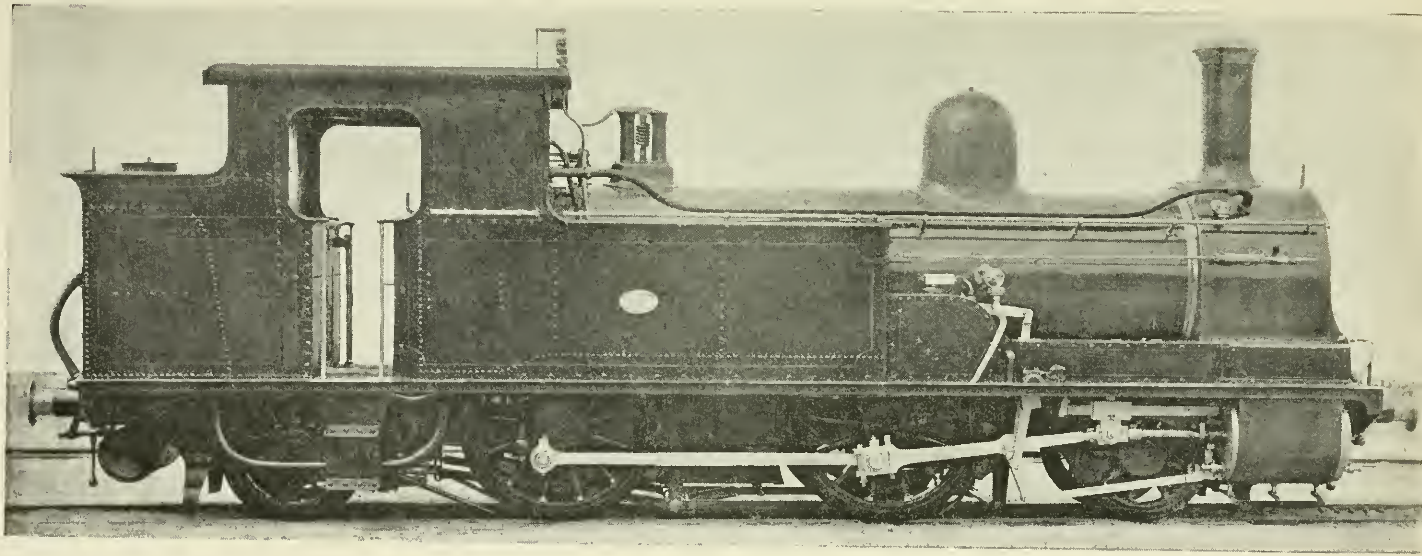
rcentages of Total Copper that are separated in Bottoms.

Mechanical Engineers 1895

JAPANESE LOCOMOTIVE BUILDING. *Plate 48.*

Fig. 1. *First Locomotive built in Japan.*

Fig. 2. *First Locomotive built in Japan.*



JAPANESE LOCOMOTIVE

Outside-cylinder Compound Tank Locomotive, No. 221.

Fig: 3. *Elevation of High-pressure side.*

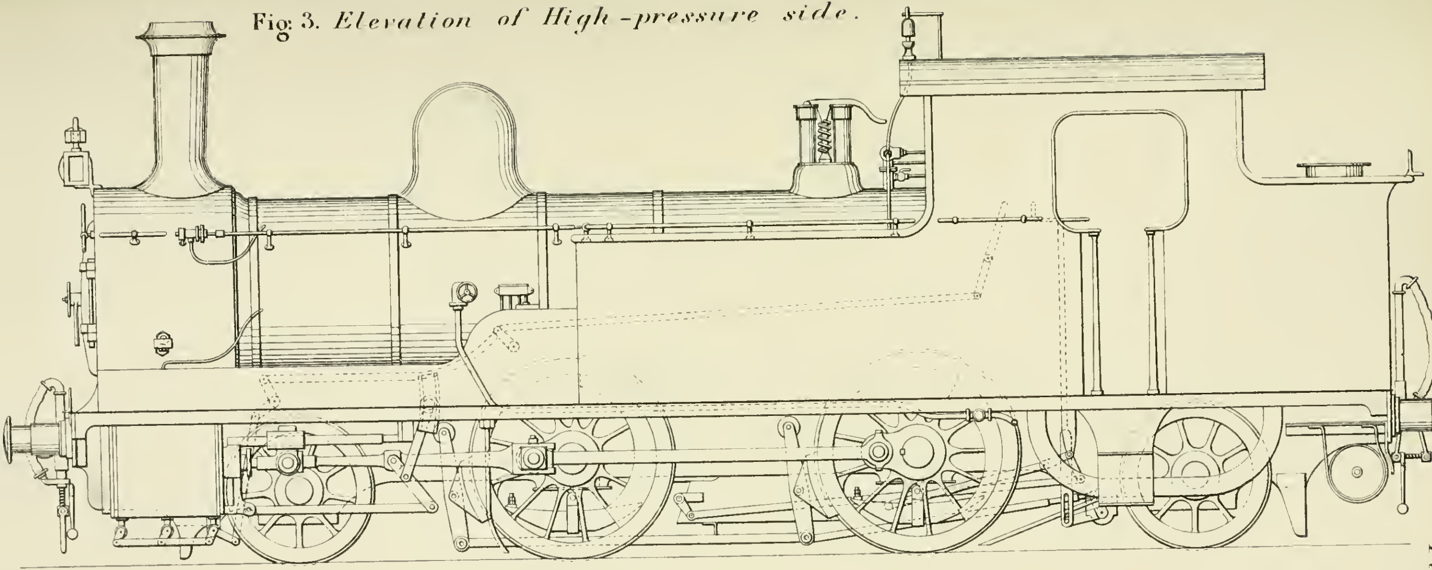


Plate 50.

Mechanical Engineers 1895.

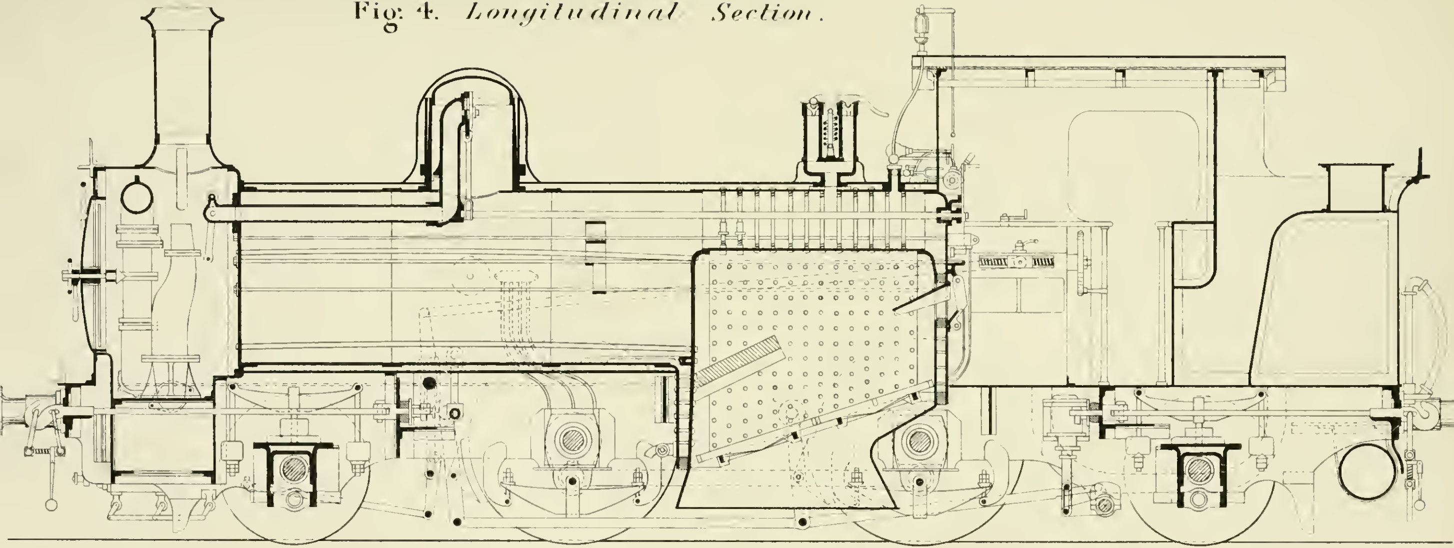
Scale 1/48th

Inches 12 6 0 5 10 15 20 25 Feet

JAPANESE LOCOMOTIVE BUILDING.

Outside-cylinder Compound Tank Locomotive, No. 221.

Fig: 4. *Longitudinal Section.*



Mechanical Engineers 1895.

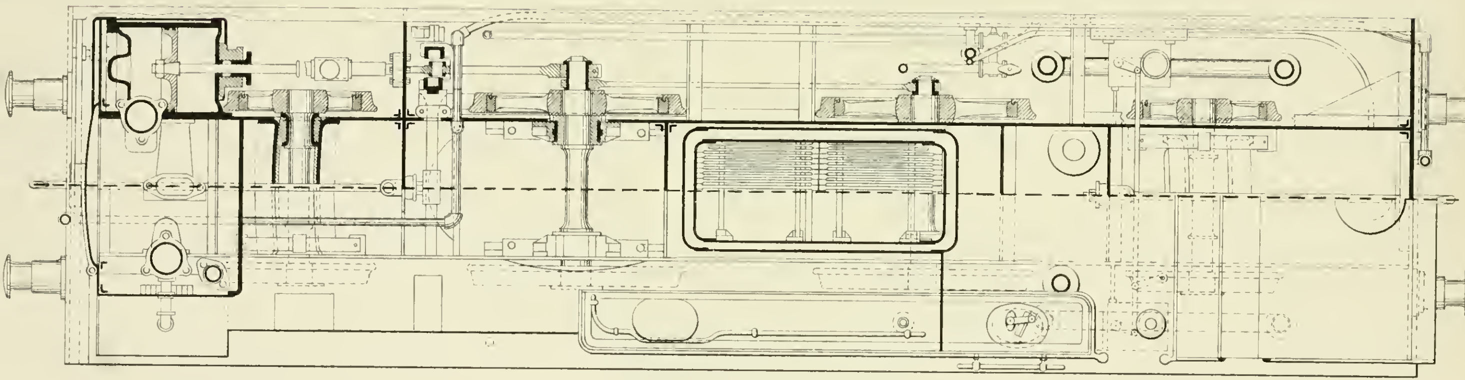
Scale 1/48th

Plate 51.

JAPANESE LOCOMOTIVE BUILDING.

Outside-cylinder Compound Tank Locomotive, No. 221.

Fig: 5. *Plan.*



Mechanical Engineers 1895.

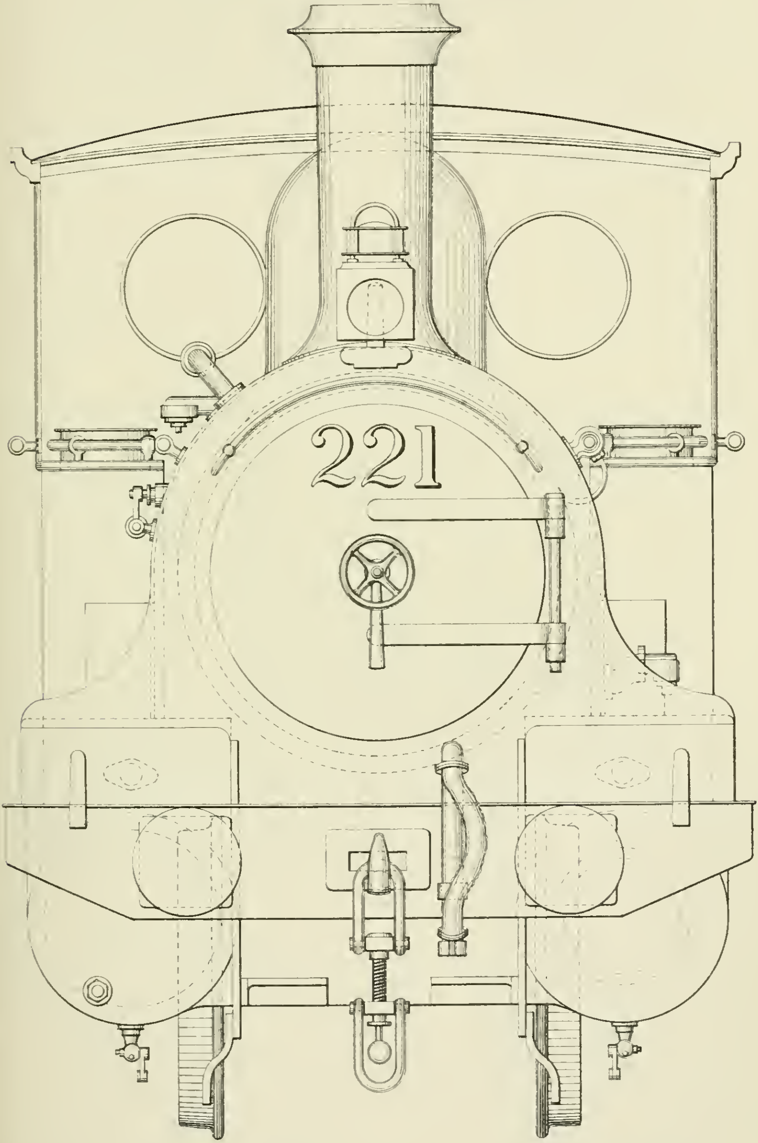
Scale 1/48th

Plate 52.

JAPANESE LOCOMOTIVE BUILDING. *Plate 53.*

Outside-cylinder Compound Tank Locomotive.

Fig. 6. *Front Elevation.*

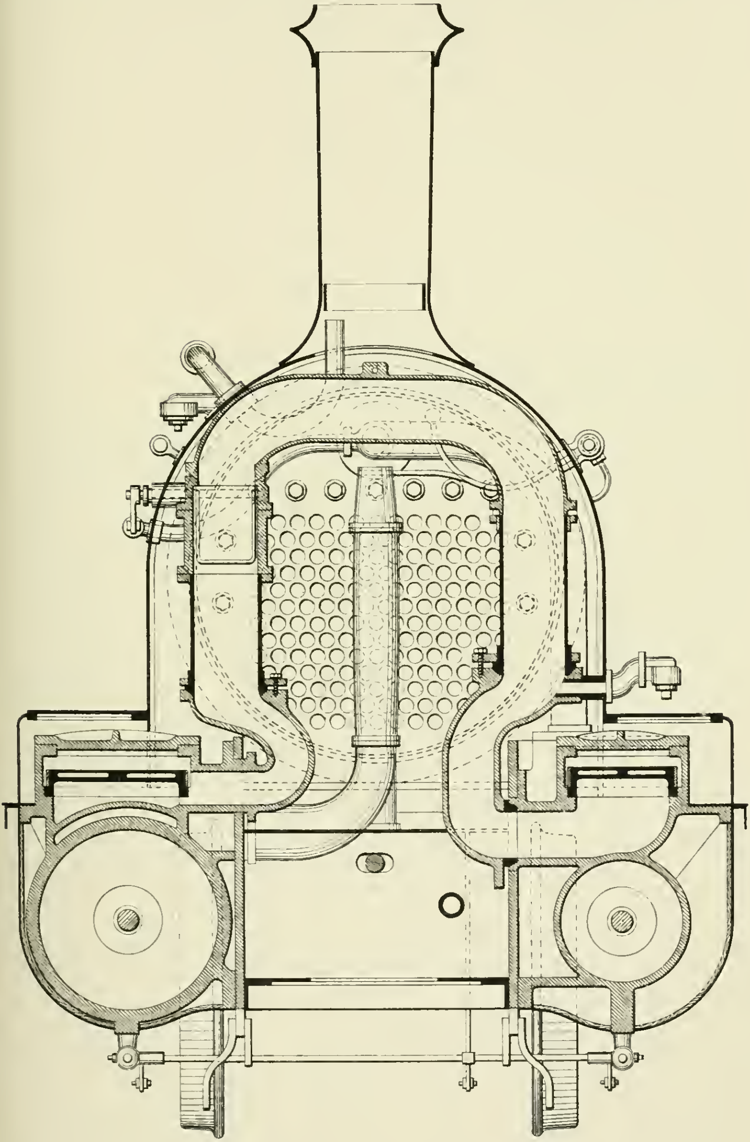


Mechanical Engineers 1895. *Scale 1/24th.*

Inches 12 6 0 1 2 3 4 5 6 Feet

ıtside-cylinder Compound Tank Locomotive, Nº 221.

Fig. 7. *Transverse Section through Smoke-box.*

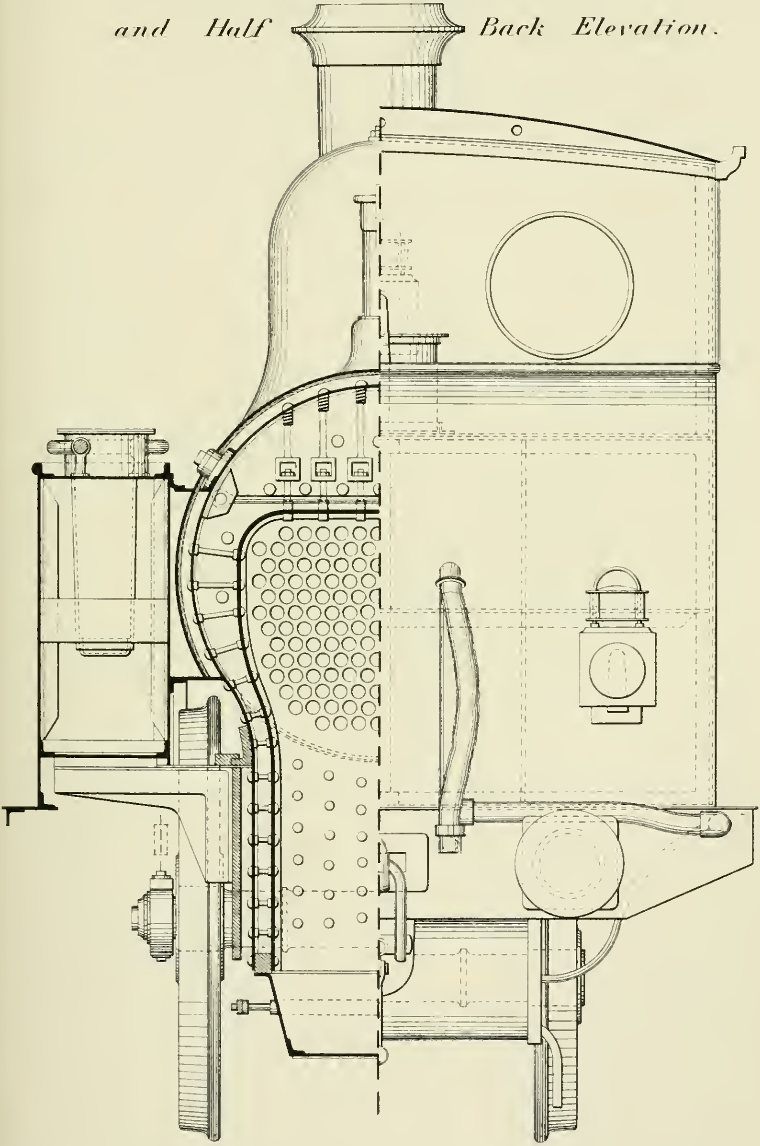


ɛchanical Engineers 1895. *Scale 1/24th.*

ches 12 6 0 1 2 3 4 5 6 Feet

)utside - cylinder Compound Tank Locomotive. No. 221.

Fig: 8. *Half Transverse Section through Fire - box and Half Back Elevation.*

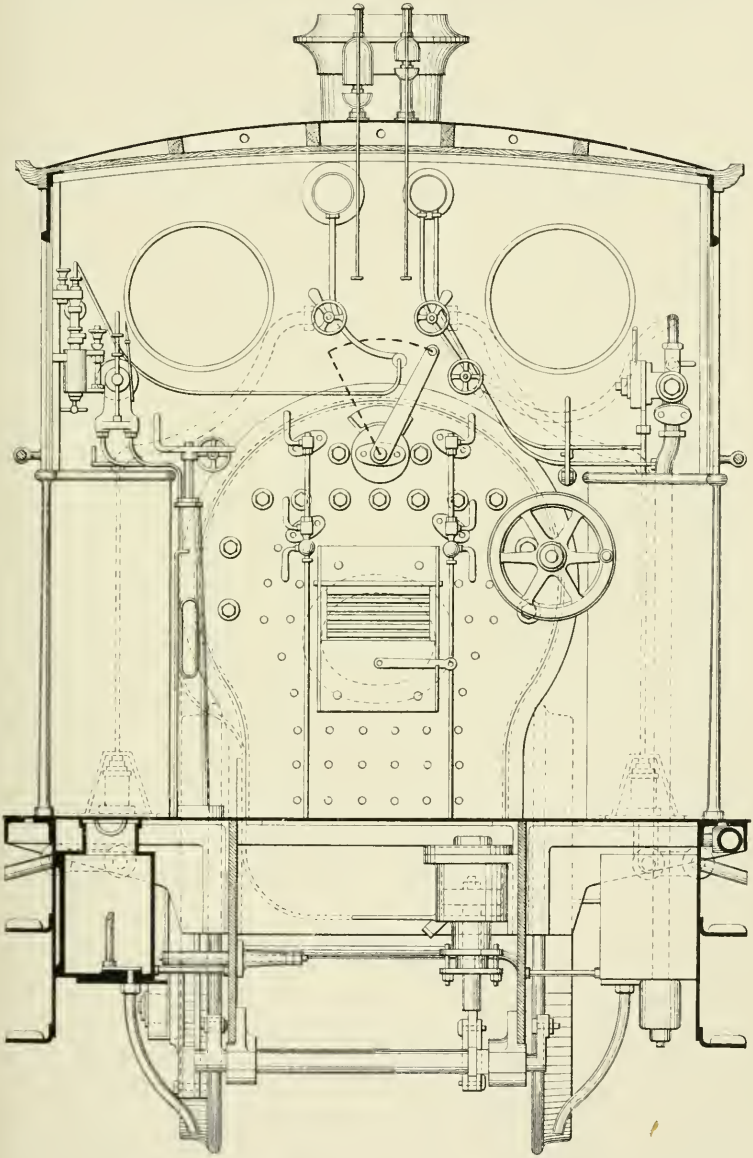


Mechanical Engineers 1895. *Scale 1/24th*

ches 12 6 0 1 2 3 4 5 6 Feet

Outside-cylinder Compound Tank Locomotive, No. 221.

Fig: 9. *Transverse Section through Footplate.*



Mechanical Engineers 1895. *Scale 1/24th*

Inches 12 6 0 1 2 3 4 5 6 *Feet*

2 A

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PARTS 3-4.

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1895.

HONORARY LIFE MEMBERS.

1890. H. R. H. Albert Edward, Prince of Wales, K.G., K.T., K.P., G.C.B., G.C.S.I., &c., Marlborough House, Pall Mall, London, S.W.

1892. Field Marshal H.R.H. the Duke of Cambridge, K.G., K.T., K.P., G.C.B., G.C.S.I., &c., Gloucester House, Park Lane, London, W.

1883. Abel, Sir Frederick Augustus, Bart., K.C.B., D.C.L., D.Sc., F.R.S., The Imperial Institute, Imperial Institute Road, London, S.W.; and 2 Whitehall Court, London, S.W. [*Imperial Institute, London.* 8743.]

1878. Crawford and Balcarres, The Right Hon. the Earl of, K.T., F.R.S., 2 Cavendish Square, London, W.; Haigh Hall, Wigan; and Observatory, Dunecht, Aberdeen.

1889. Eiffel, Gustave, 37 Rue Pasquier, Paris.

1888. Haughton, Rev. Samuel, M.D., D.C.L., LL.D., F.R.S., Trinity College, Dublin.

1883. Kennedy, Professor Alexander Blackie William, LL.D., F.R.S., 14 Old Queen Street, Westminster, S.W. [*Kinematic, London.*]

1878. Rayleigh, The Right Hon. Lord, F.R.S., 4 Carlton Gardens, London, S.W.; and Terling Place, Witham, Essex.

1888. Rosse, The Right Hon. the Earl of, K.P., D.C.L., LL.D., F.R.S., Birr Castle, Parsonstown, Ireland.

MEMBERS.

1890. Abbott, Arthur Harold, care of Messrs. Octavius Steel and Co., Calcutta India: (or care of F. C. Abbott, 101 Lambeth Palace Road, London, S.E.)

1878. Abbott, Thomas, Newark Boiler Works, Newark [*Abbott, Newark.*]; and Arlington House, Retford.

1883. Abbott, William Sutherland, Locomotive Superintendent and Assistant Engineer, Alagoas Railway, Maceio, Brazil: (or care of George S. Abbott, Lime Villa, South Woodford, Essex.)

1861. Abel, Charles Denton, Messrs. Abel and Imray, 28 Southampton Buildings, London, W.C. [*Patentable, London.* 2729.]

1874. Abernethy, James, F.R.S.E., 4 Delahay Street, Westminster, S.W.

1894. Accles, William Sloane, Redway Manufacturing Co., 44 Broadway, New York, United States.

1892. Acland, Captain Francis Edward Dyke, 76 Cheapside, London, E.C. [*Onager, London.* 15252.]

1876. Adams, Henry, 60 Queen Victoria Street, London, E.C. [*Viburnum, London.*]

1879. Adams, William, Locomotive Superintendent, London and South Western Railway, Nine Elms, London, S.W.

1848. Adams, William Alexander (*Life Member*), Gaines, Worcester.

1881. Adams, William John, 35 Queen Victoria Street, London, E.C. [*Packing, London.* 1854.]

1871. Adamson, Joseph, Messrs. Joseph Adamson and Co., Hyde, near Manchester. [*Adamson, Hyde.*]

1889. Addy, George, Waverley Works, Sheffield. [*Milling, Sheffield.*]

1887. Ahmed Bey, Colonel, Imperial Naval Arsenal, Constantinople.

1891. Ahrbecker, Henry Conrad Vandepoel, Morts Dock and Engineering Co., Balmain, Sydney, New South Wales.

1893. Ainley, Henry, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1886. Aisbitt, Matthew Wheldon, 47 Mount Stuart Square, Cardiff. [*Aisbitt, Cardiff.*]

1886. Albright, John Francis, Messrs. R. E. Crompton and Co., 4 Mansion House Buildings, Queen Victoria Street, London, E.C.; and Savernake Lodge, Chelmsford.

1885. Alderson, George Beeton, Messrs. Allen Alderson and Co., Alexandria, Egypt; Norland House, Ramleh, Alexandria, Egypt: (or care of Messrs. Stafford Allen and Sons, 7 Cowper Street, Finsbury, London, E.C.)

1881. Alexander, Edward Disney, Engineer's Department, London County Council; and 12 Cardigan Road, Richmond, Surrey.

1875. Allan, George, New British Iron Works, Corngreaves, near Birmingham; and Corngreaves Hall, near Birmingham.

1885. Allcard, Harry, Messrs. Easterbrook Allcard and Co., Albert Works, Penistone Road, Sheffield.

1874. Allen, Francis, Messrs. Allen Alderson and Co., Gracechurch Street, Alexandria, Egypt: (or care of Messrs. Stafford Allen and Sons, 7 Cowper Street, Finsbury, London, E.C.)

1891. Allen, Marcus, Union Brass and Iron Works, Great Ancoats Street, and Phœnix Iron Works, Jersey Street, Manchester. [*Valves, Manchester. Nat.* 60.]

1881. Allen, Percy Ruskin, Woodberrie Hill, Loughton, Essex.

1884. Allen, Samuel Wesley, Exchange Buildings, Mount Stuart Square, Cardiff.

1885. Allen, William Henry, Messrs. W. H. Allen Son and Co., York Street Works, Lambeth, London, S.E. [*Pump, London.*]; and Queen's Engineering Works, Bedford. [*Pump, Bedford.*]

1882. Allen, William Milward, Principal Assistant Engineer, Engine Boiler and Employers' Liability Insurance Co., 12 King Street, Manchester.

1877. Alley, Stephen, Messrs. Alley and MacLellan, Sentinel Works, Polmadie Road, Glasgow. [*Alley, Glasgow.* 673.]

1865. Alleyne, Sir John Gay Newton, Bart., Chevin, Belper.

1884. Alleyne, Reynold Henry Newton, 11 Avenue Victoria, Scarborough.

1872. Alliott, James Bingham, Messrs. Manlove Alliott and Co., Bloomsgrove Works, Ilkeston Road, Nottingham. [*Manloves, Nottingham.*]

1891. Allott, Charles Sneath, 46 Brown Street, Manchester. [*Allotted, Manchester. Nat.* 1952.]

1876. Allport, Charles James, 12 Tavistock Square, London, W.C.; and Whitehall Club, Parliament Street, Westminster, S.W.

1871. Allport, Howard Aston, Dodworth Grove, Barnsley.

1884. Almond, Harry John, Cartagena and Herrerias Steam Tramways, 43 Muralla del Mar, Cartagena, Spain: (or care of Messrs. G. and W. Almond, 67 Willow Walk, London, S.E.)

1885. Amos, Ewart Charles, Mansion House Chambers, 11 Queen Victoria Street, London, E.C.; and Eastdene, St. James' Road, Sutton, Surrey. [*Drilling, London.*]

1867. Amos, James Chapman, Rose Cottage, Fairfax Road, Teddington, S.O., Middlesex.

1891. Anderson, Alexander Southerland, Chief Engineer, Ordnance Department, Ordnance Factory, Cawnpore, India.

1880. Anderson, Edward William, Messrs. Easton, Anderson and Goolden, Erith Iron Works, Erith, S.O., Kent; and Roydon Lodge, Erith, S.O., Kent.

1890. Anderson, Herbert William, Messrs. Hilton Anderson and Co., Manor Works, Halling, near Rochester.

1892. Andersen, John Wemyss, Walker Engineering Laboratories, University College, Liverpool.

1856. Anderson, William, C.B., D.C.L., F.R.S., Director-General of Ordnance Factories, Royal Arsenal, Woolwich; and Lesney House, Erith, S. O., Kent.

1891. Anderson, William, Messrs. Head Wrightson and Co., Teesdale Iron Works, Stockton-on-Tees.

1892. Andrew, Thomas, Rand Club, Johannesburg, Transvaal, South Africa.

1895. Andrews, Thomas, Messrs. Andrews and Baby, Welsh Wagon Works, East Moors, Cardiff. [*Wagons, Cardiff.* 693.]

1893. Angas, William Moore, care of The Land Mortgage Bank of Florida, Jacksonville, Florida, United States.

1885. Anson, Frederick Henry, 15 Dean's Yard, Westminster, S.W.

1883. Appleby, Percy Vavasseur, Messrs. Jessop and Appleby Brothers, 22 Walbrook, London, E.C. [*Millwright, London.*]

1874. Aramburu y Silva, Fernando, Messrs. Aramburu and Sons, Cartridge Manufacturers, Calle de la Virgen de las Azucenas, Madrid: (or care of Manuel Cardenosa, 86 Great Tower Street, London, E.C.)

1891. Archbold, John, Eastwood Collieries, Eastwood, R.S.O., Notts.

1881. Archbold, Joseph Gibson, Manager, Blyth Dry Dock, Blyth, Northumberland.

1889. Archer, Charles Frederick, Messrs. Joseph Richmond and Co., 30 Kirby Street, Hatton Garden, London, E.C.

1874. Archer, David, 275 Pershore Road, Birmingham.

1883. Arens, Henrique, Messrs. Arens and Irmaos, Engineering Works, Rio de Janeiro, Brazil: (or care of Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough.)

1882. Armer, James, Messrs. John Birch and Co., 11 Queen Street Place, London, E.C.; and The Moorings, 108 Wickham Road, Brockley, London, S.E

1859. Armitage, William James, Farnley Iron Works, Leeds.

1894. Armour, James Glencairn, Surveyor, Bureau Veritas, Custom House Court, Newcastle-on-Tyne.

1858. Armstrong, The Right Hon. Lord, C.B., D.C.L., LL.D., F.R.S., Elswick, Newcastle-on-Tyne; and Cragside, Morpeth.

1866. Armstrong, George, Locomotive Department, Great Western Railway, Stafford Road Works, Wolverhampton.

1882. Armstrong, George Frederick, F.R.S.E., Professor of Engineering, The University, Edinburgh.

1876. Armstrong, William, Jun., Mining Engineer, Wingate Colliery, County Durham.

1870. Armstrong, William Irving, Timber Works and Saw Mills, 17 North Bridge Street, Sunderland.

1894. Arnot, William, Glasgow Corporation Electric Lighting Station, 75 Waterloo Street, Glasgow. [*Induction, Glasgow.* 4665.]

1887. Arrol, Sir William, M.P., LL.D., Dalmarnock Iron Works, Glasgow.

1887. Arteaga, Alberto de, Libertad 1357, Buenos Aires, Argentine Republic: (or care of M. Raggio-Carneiro, 129A Winchester House, Old Broad Street, London, E.C.)

1873. Ashbury, Thomas (*Life Member*), 5 Market Street, Manchester; and Ash Grove, Victoria Park, Longsight, Manchester. [*Thomas Ashbury, Manchester.*]

1888. Ashby, George, Tardeo, Bombay, India.

1895. Ashcroft, Andrew George, Principal, Woolwich Polytechnic, William Street, Woolwich; and 6 St. Margaret's Road, Plumstead.

1890. Ashley, Thomas James, Messrs. Fawcett Preston and Co., Phœnix Foundry, Liverpool.

1884. Ashwell, Frank, Messrs. Ashwell and Nesbit, Victoria Foundry, Sycamore Lane, Leicester. [*Iron, Leicester.* 100.]

1891. Ashworth, Henry, The Villa, Llangorse, Talgarth, R.S.O., Breconshire.

1890. Askham, John Unwin, Messrs. Askham Brothers and Wilson, Yorkshire Steel Works, Napier Street, Sheffield.

1890. Askham, Philip Unwin, Messrs. Askham Brothers and Wilson, Yorkshire Steel Works, Napier Street, Sheffield.

1881. Aspinall, John Audley Frederick, Chief Mechanical Engineer, Lancashire and Yorkshire Railway, Horwich, near Bolton; and Fern Bank, Heaton, Bolton.

1891. Asplen, Bernard, Southall: (or care of W. W. Asplen, Foxton Hall, Royston, Cambridgeshire.)

1877. Astbury, James, Smethwick Foundry, near Birmingham.

1890. Aston, John W., Chief Teacher of Mechanical Science, Municipal School of Art, Birmingham; and Messrs. G. E. Belliss and Co., Ledsam Street, Birmingham.

1886. Atkey, Albert Reuben, 199 Sherwood Street, Nottingham.

1889. Atkinson, Alexander, Jammu, Kashmir, India: (or care of Messrs. Grindlay and Co., 55 Parliament Street, Westminster, S.W.)

1875. Atkinson, Edward (*Life Member*), Messrs. Bramwell and Harris, 5 Great George Street, Westminster, S.W.; and 32 Park Road, West Dulwich, London, S.E.

1890. Atkinson, Edward Turner, London County Council, Spring Gardens, London, S.W.

1892. Atkinson, James, The Woodlands, Marple, near Stockport.

1892. Ault, Edwin, 47 Victoria Street, Westminster, S.W.

1892. Austin, James Meredith, 51 Waldeck Avenue, Bedford.

1882. Aveling, Thomas Lake, Messrs. Aveling and Porter, Rochester. [*Aveling, Rochester.*]

1891. Bagshaw, Walter, Victoria Foundry, Batley.

1886. Bailey, William, 14 Delahay Street, Westminster, S.W.

1885. Bailey, Sir William Henry, Albion Works, Salford, Manchester [*Beacon, Salford.*]; and Sale Hall, Cheshire.

1872. Bailly, Philimond, 282 Rue Royale, Bruxelles, Belgium.

1890. Bain, George, Locomotive Department, Egyptian Government Railways, Cairo, Egypt.

1880. Bain, William Neish, 40 St. Enoch Square, Glasgow; and Collingwood, 7 Aytoun Road, Pollokshields, Glasgow. [*Glacis, Glasgow.*]

1869. Bainbridge, Emerson, M.P., Nunnery Colliery Offices, New Haymarket, Sheffield.

1873. Baird, George, St. Petersburg; and Fulmer, Slough.

1890. Baker, Sir Benjamin, K.C.M.G., LL.D., F.R.S. (*Life Member*), 2 Queen Square Place, Westminster, S.W.

1875. Bakewell, Herbert James, Engineer, Department of the Controller of the Navy, Admiralty, Whitehall, London, S.W.

1893. Baldwin, Alfred, M.P., Wilden Iron Works, Stourport.

1894. Baldwin, Arthur Hugh, Messrs. Kendall and Gent, Victoria Works, Springfield, Salford, Manchester. [*Tools, Manchester.* Nat. 330; Mutual 1330.]

1877. Bale, Manfred Powis, Appold Street, Finsbury, London, E.C.

1884. Balmokand, Rai Bahadur, Executive Engineer, 4th Division, Chenab Canal, Lahore, Punjaub, India.

1887. Bamlett, Adam Carlisle, Agricultural Engineering Works, Thirsk.

1892. Banister, George Henry, Carriage Department, Royal Arsenal, Woolwich.

1885. Barker, Tom Birkett, Scholefield Street, Birmingham. [*Gasengine, Birmingham.* 2530.]

1880. Barlow-Massicks, Thomas, Millom Iron Works, Millom, Cumberland.

1891. Barnes, John Edward Lloyd, Messrs. Sloan and Lloyd Barnes, Castle Chambers, 26 Castle Street, Liverpool. [*Technical, Liverpool.*]

1881. Barnett, John Davis, Assistant Mechanical Superintendent, Grand Trunk Railway, Stratford, Ontario, Canada.

1887. Barningham, James, 41 Victoria Buildings, Victoria Street, Manchester.

1884. Barr, Archibald, D.Sc., Professor of Engineering, The University, Glasgow.

1882. Barrett, John James, 5 Chinchpoogly Road, Bombay, India.

1885. Barrie, William, Superintendent Engineer, Nippon Yusen Kaisha Steam Ship Co., 266 Bluff, Yokohama, Japan.

1887. Barringer, Herbert, 88 Bishopsgate Street Within, London, E.C.

1862. Barrow, Joseph, Messrs. Thomas Shanks and Co., Johnstone, near Glasgow. [*Shanks, Johnstone.*]

1871. Barry, John Wolfe, C.B., F.R.S., 21 Delahay Street, Westminster, S.W. [*Consilium, London.* 3024.]

1883. Bartlett, James Herbert, Middlesbrough, Kentucky, United States.

1887. Bate, Major Charles McGuire, R.E., Royal Engineers' Office, Mauritius.

1885. Bateman, Henry, Superintending Engineer, Rangoon Tramways, Rangoon, India.

1891. Bates, Henry, Messrs. Hulse and Co., Ordsal Works, Regent Bridge, Salford, Manchester; and 30 Halliwell Terrace, Trafford Road, Salford, Manchester.

1892. Baxter, Peter Macleod, Messrs. McKie and Baxter, Copland Works, Govan, Glasgow.

1889. Bayford, William James, Engineer and Manager, Messrs. Meakin and Co., Brewers, Delhi, India.

1872. Bayliss, Thomas Richard, Belmont, Northfield, Birmingham.

1891. Baynes, John, Midland Railway-Carriage and Wagon Co., Suffolk House, Laurence Pountney Hill, London, E.C.

1877. Beale, William Phipson, Q.C., 10 New Court, Carey Street, London, W.C.; and 19 Upper Phillimore Gardens, Kensington, London, W.

1895. Beard, Bernard, Messrs. Francis Morton and Co., Hamilton Iron Works, Garston, near Liverpool.

1887. Beardmore, William, Parkhead Forge and Steel Works, Glasgow.

1893. Beare, Thomas Hudson, F.R.S.E., Professor of Engineering, University College, Gower Street, London, W.C.

1893. Beastow, William Henry, Messrs. Brooks and Doxey, Union Iron Works, West Gorton, Manchester; and Junction Iron Works, Miles Platting, Manchester; and 157 Hyde Road, West Gorton, Manchester.

1891. Beatty, Hazlitt Michael, Locomotive Superintendent, Western Railway, Cape Government Railways, Salt River, near Cape Town, Cape Colony; and Rosclare Camp Ground, Rondebosch, near Cape Town, Cape Colony.

1880. Beaumont, William Worby, 33 Norfolk Street, Strand, London, W.C.; and Melford, Palace Road, Tulse Hill, London, S.W.

1859. Beck, Edward (*Life Member*), Dallam Forge, Warrington; and Springfield, Warrington.

1873. Beck, William Henry, 115 Cannon Street, London, E.C.

1887. Beckwith, George, Enfield House, Fairlop Road, Leytonstone, London, N.E.

1875. Beckwith, John Henry, Managing Director, Messrs. Galloways, Knott Mill Iron Works, Manchester.

1882. Bedson, Joseph Phillips, Parkhurst, Middlesbrough.

1875. Beeley, Thomas, Engineer and Boiler Maker, Hyde Junction Iron Works, Hyde, near Manchester. [*Beeley, Hyde.*]

1888. Beldam, Asplan, 77 Gracechurch Street, London, E.C.

1885. Bell, Charles Lowthian, Clarence Iron Works, Middlesbrough; and Linthorpe, Middlesbrough. [*Bells, Middlesbrough.* 5510.]

1858. Bell, Sir Lowthian, Bart., F.R.S., Clarence Iron Works, Middlesbrough; Rounton Grange, Northallerton; and Reform Club, Pall Mall, London, S.W. [*Sir Lowthian Bell, Middlesbrough.*]

1879. Bellamy, Charles James, 9 Wetherby Terrace, South Kensington, London, S.W.

1868. Belliss, George Edward, Steam Engine and Boiler Works, Ledsam Street, Birmingham [*Belliss, Birmingham.*]; and The Dell, King's Norton, near Birmingham.

1878. Belsham, Maurice, Messrs. Price and Belsham, 52 Queen Victoria Street, London, E.C.

1880. Benham, Percy, Messrs. Benham, 66 Wigmore Street, London, W. [*Benham, London.* 7065.]

1895. Benn, Sykes, Messrs. S. S. Stott and Co., Haslingden, near Manchester. [*Elevator, Haslingden.* 103.]

1894. Bennett, James William, Messrs. Taylor and Lawson, Engineering Works, Batavia; and Alington, Dean Park, Bournemouth.

1895. Bennington, John William, Staff Engineer, R.N., 29 Roebuck Road, Rochester.

1895. Bennion, Charles, Messrs. Pearson and Bennion, Union Works, Leicester; and Danes Hill House, Hinckley Road, Leicester. [*Prominent, Leicester.* 103.]

1894. Bentley, George, Messrs. Bentley and Jackson, Lodge Bank Works, Bury, Lancashire.

1895. Berchem, Alphonse Henry Emanuel, Worthington Pumping Engine Co., 153 Queen Victoria Street, London, E.C.

1890. Berkley, James Eustace, Locomotive and Carriage Superintendent, H.H. the Nizam's Guaranteed State Railways, Secunderabad, India.

1878. Berrier-Fontaine, Marc, Directeur des Constructions navales, Toulon, France.

1893. Berry, Henry, Croydon Works, Leeds.

1893. Berry, John Ferrier, care of Messrs. Howard Farrar and Co., P. O. Box 455, Johannesburg, Transvaal, South Africa.

1890. Bertram, Alexander, Wigan Coal and Iron Works, Wigan.

1891. Bertram, David Noble, Messrs. Bertrams, St. Katherine's Works, Sciennes, Edinburgh.

1861. Bessemer, Sir Henry, F.R.S., Denmark Hill, London, S.E.

1891. Best, Francis Edward, 1 Swan Walk, Chelsea Embankment, London, S.W.

1893. Betts, Samuel, Locomotive Superintendent, Oxelösund-Fleu-Westmanlands Railway, Eskilstuna, Sweden.

1891. Bevis, Alfred William, The Nest, Harborne, Birmingham.

1866. Bevis, Restel Ratsey, Messrs. Laird Brothers, Birkenhead Iron Works, Birkenhead; and Manor Hill, Birkenhead.

1892. Bickle, Thomas Edwin, Messrs. Bickle and Co., Great Western Docks, Plymouth. [*Engineers, Plymouth.* 176.]

1885. Bicknell, Arthur Channing, 42 Pelham Street, South Kensington, London, S.W.

1883. Bicknell, Edward, care of Bank of Bengal, Calcutta, India: (or 8 Canynge Square, Clifton, Bristol.)

1884. Bika, Léon Joseph, Locomotive Engineer-in-Chief, Belgian State Railway, 29 Rue des Palais, Bruxelles, Belgium.

1888. Billinton, Robert John, Locomotive Superintendent, London Brighton and South Coast Railway, Brighton.

1890. Bingham, Charles Henry, Messrs. Walker and Hall, Electro Works, Howard Street, Sheffield. [*Bingham, Sheffield.*]

1887. Binnie, Alexander Richardson, Engineer, London County Council, Spring Gardens, London, S.W.; and 77 Ladbroke Grove, Notting Hill, London, W.

1877. Birch, Robert William Peregrine, 5 Queen Anne's Gate, Westminster, S.W.

1891. Bird, George, Messrs. James Bartle and Co., Western Iron Works, Notting Hill, London, W.

1880. Birkett, Herbert, 91 Victoria Street, Westminster, S.W.

1879. Black, William, Messrs. Black Hawthorn and Co., Gateshead. [*Blackthorn, Newcastletyne.*]

1891. Black, William, 72 Bute Road, Cardiff.

1891. Blackburn, Arthur Henry, Fuel Economizer Co., Matteawan, New York, United States.

1891. Blackburn, George William, Messrs. T. Green and Son, Smithfield Iron Works, Leeds.

1890. Blackburn, John, Resident Engineer, Colne Valley Water Works, Bushey, Watford.

1862. Blake, Henry Wollaston, F.R.S., Messrs. James Watt and Co., 90 Leadenhall Street, London, E.C.

1886. Blandford, Thomas, Corbridge, R.S.O., Northumberland.

1881. Blechynden, Alfred, Naval Construction and Armaments Works, Barrow-in-Furness.

1892. Bleehynden, John, Shanghai Engine Works, Birt's Wharf, Shanghai, China. [*Steam, Shanghai.* 176.]

1867. Bleckly, John James, Bewsey Iron Works, Warrington; and Daresbury Lodge, Altrincham.

1882. Blundstone, Samuel Richardson, Catherine Chambers, 8 Catherine Street, Strand, London, W.C.

1884. Bocquet, Harry Claude, Locomotive Carriage and Wagon Superintendent, North West Argentine Railway, Tucuman, Argentine Republic: (or care of Mrs. Bocquet, Llanwye, Hampton Park, Hereford.)

1863. Boeddinghaus, Julius, Electrotechniker, Düsseldorf, Germany.

1895. Bond, George Creswell, Newcastle Chambers, Nottingham. [*Bonds, Nottingham.* 441.]

1884. Bone, William Lockhart, Works of the Ant and Bee, West Gorton, Manchester.

1895. Boorman, Joseph Ashworth, Messrs. Greenwood and Batley, Albion Works, Leeds.

1892. Booth, John William, Union Foundry, Rodley, near Leeds.

1890. Booth, Robert, Messrs. Booth and Ravenshaw, 110 Cannon Street, London, E.C.

1880. Borodin, Alexander, Engineer-Director, Russian South Western Railways, Kieff, Russia.

1888. Borrows, William, Messrs. Edward Borrows and Sons, Providence Foundry, Sutton, St. Helen's, Lancashire.

1891. Boswell, Samuel, Messrs. Galloways, Knott Mill Iron Works, Manchester.

1888. Boulding, Sidney, Messrs. Green and Boulding, 21 Featherstone Street, London, E.C. [*Temperature, London.*]

1886. Boult, Alfred Julius, Messrs. Boult and Wade, 111 Hatton Garden, London, E.C. [*Boult, London.* 2896.]

1878. Bourdon, François Edouard, 74 Faubourg du Temple, Paris: (or care of Messrs. Negretti and Zambra, Holborn Viaduct, London, E.C.)

1886. Bourne, Thomas Johnstone, Imperial Chinese Railways, Tientsin, China: (or care of Mrs. Bourne, 16 Park Road, Southborough, Tunbridge Wells.)

1879. Bourne, William Temple, Messrs. Bourne and Grove, Bridge Steam Saw Mills, Worcester.

1891. Bousfield, John Ebenezer, 4 South Street, Finsbury, London, E.C. [*Invention, London.* 169.]

1879. Bovey, Henry Taylor, LL.D., Professor of Engineering, McGill University, Montreal, Canada.

1880. Bow, William, Messrs. Bow McLachlan and Co., Thistle Engine Works, Paisley. [*Bow, Paisley.*]

1888. Bowen, Edward (*Life Member*), 18 Upper Wellington Road, Brighton.

1858. Bower, John Wilkes (*Life Member*), Meredale, Rugby Road, Leamington Spa.

1892. Bowker, Arthur F., Engineer, Mid-Kent Water Works, Snodland, S.O., Kent.

1893. Boyd, James Tennant, Boyd's Ice Factory, Bombay, India.

1890. Boyd, John White, 6 Oswald Street, Glasgow. [*Silent, Glasgow.*]

1884. Boyer, Robert Skeffington, 46 Mount Stuart Square, Cardiff.

1882. Bradley, Frederic, Sandhills, Liverpool; Clensmore Foundry, Kidderminster; and Wolverley House, Southport.

1878. Braithwaite, Charles C., 35 King William Street, London Bridge, London, E.C.

1875. Braithwaite, Richard Charles, Messrs. Braithwaite and Kirk, Crown Bridge Works, Westbromwich [*Braithwaite, Westbromwich.*]; and 39 Victoria Street, Westminster, S.W.

1854. Bramwell, Sir Frederick Joseph, Bart., D.C.L., LL.D., F.R.S., Messrs. Bramwell and Harris, 5 Great George Street, Westminster, S.W. [*Wellbram, London.* 3060.]

1892. Brand, David Jollie, Messrs. Brand and Dryburgh, Cleveland Foundry and Engine Works, Townsville, North Queensland.

1888. Bratt, Augustus Hicks Henery, Le Kueh Coal and Iron Mines, Kiangsu, North China; Astor House, Shanghai, China: (or care of Messrs. J. H. Bower and Co., 138 Leadenhall Street, London, E.C.) [*Bratt, Shanghai.*]

1895. Bratt, Edward Hicks Fraser, Messrs. Bratt and Gibson, Taiping, Perak, Straits Settlements.

1885. Brearley, Benjamin J., Union Plate Glass Works, St. Helen's; and The Laurels, Queen's Park, St. Helen's.

1889. Brebner, Samuel Gordon, Chief Mechanical Engineer, Small Arms Ammunition Factory, Kirkee, Poona, India; and 2 Swallowfield Road, Charlton, Kent.

1891. Brewster, Edwin Henry George, 12 Delahay Street, Westminster, S.W.

1890. Brewster, Walter Seckford, Messrs. Beyer Peacock and Co.; Wrentham, Fleet Street, Carlton, near Sydney, New South Wales.

1887. Brier, Henry, Messrs. J. H. Carruthers and Co., Hamilton Street, Polmadie, Glasgow.

1889. Briggs, Charles, care of Robert Briggs, Howden.

1881. Briggs, John Henry, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W.; and Howden.

1886. Bright, William, Manager, Fairwood Tin-Plate Works, Gowerton, R.S.O., Glamorganshire.

1894. Brindley, George Samuel, Cliffe House, Smethwick, near Birmingham.

1895. Britten, Thomas Johnson, P.O. Box 494, Johannesburg, Transvaal, South Africa.

1891. Broadbent, William, Messrs. Thomas Broadbent and Sons, Central Iron Works, Huddersfield. [*Broadbent, Huddersfield.* 102.]

1891. Brock, Cameron William Harrison, 10 Delahay Street, Westminster, S.W.

1865. Brock, Walter, Messrs. Denny and Co., Engine Works, Dumbarton. [*Lennox, Dumbarton.* 1 and 15.]

1890. Brodie, John Alexander, 3 Cook Street, Liverpool.

1852. Brogden, Henry (*Life Member*), Hale Lodge, Altrincham, near Manchester.

1890. Brogden, Thomas, Messrs. Appleby and Brogden, Sandside, Scarborough.

1892. Bromiley, William J., Messrs. Dobson and Barlow, Kay Street Machine Works, Bolton.

1892. Brooke, John Walter, Adrian Iron Works, Lowestoft.

1892. Brooke, Robert Grundy, Messrs. Holden and Brooke, St. Simon's Works, Salford, Manchester. [*Influx, Manchester.*]

1884. Brook-Fox, Frederick George, 2 Comeragh Road, Baron's Court, West Kensington, London, W.

1880. Brophy, Michael Mary, Messrs. James Slater and Co., 251 High Holborn, London, W.C.

1874. Brotherhood, Peter, 15 and 17 Belvedere Road, Lambeth, London, S.E.; and 15 Hyde Park Gardens, London, W. [*Brotherhood, London.*]

1886. Brown, Andrew, 110 Cannon Street, London, E.C.; and Willis Road, Erith, S.O., Kent.

1866. Brown, Andrew Betts, F.R.S.E., Messrs. Brown Brothers and Co., Rosebank Iron Works, Edinburgh.

1891. Brown, Arthur Mogg, P.O. Box 491, Johannesburg, Transvaal, South Africa.

1885. Brown, Benjamin, Widnes Foundry, Widnes.

1880. Brown, Francis Robert Fountaine, Mechanical Superintendent, Intercolonial Railway of Canada, Moncton, New Brunswick, Canada.

1889. Brown, Lieutenant Frederick Alexander William, R.A., Inspector of Ordnance Machinery, The Castle, Cape Town, Cape Colony: (or 42 Fermoy Road, St. Peter's Park, London, W.)

1881. Brown, George William, Messrs. Huntley Boorne and Stevens, Reading Tin Works, Reading. [251.]

1892. Brown, James Fiddes, 147 Woodbridge Road, Ipswich.

1884. Brown, Oswald, 32 Victoria Street, Westminster, S.W. [*Acqua, London.*]

1890. Brown, Robert, Manor House Engine Works, Far Cotton, Northampton.

1888. Brown, William, Messrs. W. Simons and Co., London Works, Renfrew.

1892. Brown, William, Messrs. Siemens Brothers and Co., Woolwich.

1874. Browne, Tomyns Reginald, Deputy Locomotive Superintendent, East Indian Railway, Jamalpur, Bengal, India: (or care of Mrs. Browne, care of A. C. Brett, Mozufferpore, East Liss, Hants.

1874. Bruce, Sir George Barclay, 3 Victoria Street, Westminster, S.W.

1889. Bruce, Robert, 30 Great St. Helen's, London, E.C. [*Tangential, London.*]

1867. Bruce, William Duff, 17 Victoria Street, Westminster, S.W.; and 23 Roland Gardens, South Kensington, London, S.W.
1888. Bruff, Charles Clarke, Coalport China Co., Coalport, near Ironbridge, Salop.
1873. Brunel, Henry Marc, 21 Delahay Street, Westminster, S.W. [3024.]
1892. Brunlees, John, 12 Victoria Street, Westminster, S.W. [3245.]
1891. Brunner, Adolphus, 55 Am Königin Strasse, Munich, Bavaria: (or care of L. F. Brunner, 257 Romford Road, Forest Gate, London, E.)
1887. Brunton, Philip George, Resident Engineer, Department of Roads and Bridges, Public Works Office, Sydney, New South Wales: (or care of J. D. Brunton, 19 Great George Street, Westminster, S.W.)
1884. Bryan, William B., Engineer, East London Water Works, Lea Bridge, Clapton, London, N.E.
1892. Buckley, John T., Messrs. Stevenson and Co., Canal Foundry, Preston; and 50 Poulton Street, Kirkham, near Preston.
1877. Buckley, Samuel, Messrs. Buckley and Taylor, Castle Iron Works, Oldham.
1895. Buckley, Victor Emanuel, Managing Director, Riga Spinning and Thread Works, Strasdenhof, Riga, Russia.
1886. Buckney, Thomas, Messrs. E. Dent and Co., 61 Strand, London, W.C.
1887. Buckton, Walter, 27 Ladbroke Square, London, W.
1878. Buddicom, Harry William, Penbedw, Nannerch, near Mold.
1886. Budenberg, Christian Frederick, Messrs. Schäffer and Budenberg, 1 Southgate, St. Mary's Street, Manchester; and Bowden Lane, Marple, Stockport. [*Manometer, Manchester.* 899.]
1882. Budge, Enrique, Engineer-in-Chief, Harbour Works, Valparaiso, Chile: (or care of Messrs. Rose-Innes Cox and Co., 4 Fenchurch Avenue, London, E.C.)
1881. Bulkley, Henry Wheeler, N.Y. Times Building, 41 Park Row, New York, United States.
1884. Bullock, Joseph Howell, General Manager, Pelsall Coal and Iron Works, near Walsall; and Glenhurst, Lichfield Road, Walsall.
1882. Bulmer, John, Spring Garden Engineering Works, Pitt Street, Newcastle-on-Tyne.
1891. Bumsted, Francis Dixon, Cannock Chase Foundry and Engine Works, Hednesford, near Stafford.
1884. Bunt, Thomas, Superintendent Engineer, Kiangnan Arsenal, Shanghai, China: (or care of R. Pearce, Lanarth House, Holders Hill, Hendon, London, N.W.)
1884. Bunting, George Albert, Locomotive Superintendent, Estrada de Ferro Recife e São Francisco, Pernambuco, Brazil.
1885. Burder, Walter Chapman, Messrs. Messenger and Co., Loughborough.
1891. Burgess, Francis Chassereau Boughey, Office of Director General of Railways, Technical Section, Simla, India.

1894. Burke, Michael James, Locomotive and Carriage Superintendent, Morvi Railway, Morvi, India.

1881. Burn, Robert Scott, Oak Lea, Edgeley Road, near Stockport.

1893. Burnes, Thomas, Fleet Engineer, R.N., H.M.S. "Ajax," Chatham.

1879. Burnet, Lindsay, Moore Park Boiler Works, Govan, near Glasgow. [*Burnet, Glasgow.* 1513.]

1878. Burnett, Robert Harvey, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1878. Burrell, Charles, Jun., Messrs. Charles Burrell and Sons, St. Nicholas Works, Thetford. [*Burrell, Thetford.*]

1885. Burrell, Frederick John, Messrs. Charles Burrell and Sons, St. Nicholas Works, Thetford. [*Burrell, Thetford.*]

1887. Burstal, Edward Kynaston, Messrs. Stevenson and Burstal, 38 Parliament Street, Westminster, S.W.

1890. Burstall, Henry Robert John, 14 Old Queen Street, Westminster, S.W.; and 76 King's Road, London, N.W.

1884. Butcher, Joseph John, P. O. Box 132, Thompsonville, Connecticut, United States.

1882. Butler, Edmund, Kirkstall Forge, near Leeds. [*Forge, Kirkstall.*]

1892. Butler, Henry William, Messrs. F. A. Robinson and Co., 54 Old Broad Street, London, E.C.

1884. Butler, Hugh Myddleton, Kirkstall Forge, near Leeds.

1891. Butler, James, Victoria Iron Works, Halifax; and Longfield, Halifax.

1888. Butter, Frederick Henry, Carriage Department, Royal Arsenal, Woolwich; and 4 Hanover Road, Brookhill Park, Plumstead.

1891. Butter, Henry Joseph, Messrs. Tannett Walker and Co., Leeds; and Claremont, Burrage Road, Plumstead.

1894. Butterworth, Joseph, Messrs. Lancaster and Tonge, Pendleton, Manchester.

1892. Byrne, Francis Furlong, Engineer, Harbour Office, Drogheda, Ireland. [*Byrne, Engineer, Drogheda.*]

1887. Caiger, Emery John, Messrs. E. J. Caiger and Co., 77 Billiter Buildings, Billiter Street, London, E.C. [*Caiger, London.*]

1886. Cairnes, Frederick Evelyn, Bridgewater Hotel, Worsley, near Manchester.

1889. Callan, William, River Plate Fresh Meat Co., 2 Coleman Street, London, E.C.

1886. Cambridge, Henry, Stuart Chambers, Mount Stuart Square, Cardiff.

1893. Campbell, Andrew Chisholm, Messrs. James Campbell and Sons, Vulcan Engine Works, William Moult Street, Liverpool.
1877. Campbell, Angus, Logie, Mussoorie, N. W. Provinces, India.
1880. Campbell, Daniel, Messrs. Campbell, Macmaster and Co., 11 and 12 Clement's Lane, Lombard Street, London, E.C. [*Duke, London.* 2011.]
1869. Campbell, James, Hunslet Engine Works, Leeds. [*Engineco, Leeds.*]
1893. Campbell, James Alexander Miller, Messrs. James Campbell and Sons, Vulcan Engine Works, William Moult Street, Liverpool.
1882. Campbell, John, Messrs. R. W. Deacon and Co., Kalimaas Works, Soerabaya, Java.
1892. Campbell, William Walker, Messrs. Campbell and Calderwood, Soho Engine Works, Paisley. [*Soho, Paisley.* 162.]
1885. Capito, Charles Alfred Adolph, 2 Penywern Road, Earl's Court, London, S.W.
1892. Capper, David Sing, Professor of Mechanical Engineering, King's College, Strand, London, W.C.
1860. Carbutt, Sir Edward Hamer, Bart., 19 Hyde Park Gardens, London, W.; and Nanhurst, Cranleigh, Guildford.
1878. Cardew, Cornelius Edward, Locomotive and Carriage Superintendent, Burma State Railways, Insein, Burma; care of Messrs. King King and Co., Bombay, India: (or care of Rev. J. H. Cardew, Wingfield Rectory, Trowbridge.)
1875. Cardozo, Francisco Corrêa de Mesquita (*Life Member*), Messrs. Cardozo and Irmâo, Pernambuco Engine Works, Pernambuco, Brazil: (or care of Messrs. Fry Miers and Co., 8 Great Winchester Street, London, E.C.)
1892. Carnegie, David, Royal Laboratory, Royal Arsenal, Woolwich.
1866. Carpmael, William, 24 Southampton Buildings, London, W.C. [*Carpmael, London.* 2608.]
1877. Carr, Robert, 1 West Pier, London Docks, London, E.
1895. Carr, Robert Alfred, Resident Engineer, Port Talbot Railway and Docks, Port Talbot. [*Carr, Port Talbot.* 485.]
1892. Carrack, Charles, Messrs. Crossley Brothers, 116 New Street, Birmingham.
1884. Carrick, Henry, Messrs. Carrick and Wardale, Redheugh Engine Works, Gateshead; and Newbrough Lodge, Fourstones, R.S.O., Northumberland. [*Wardale, Gateshead.*]
1885. Carter, Herbert Fuller, Calle de Gante 11, Ciudad de Mexico, Mexico: (or care of H. Maynard Carter, 79 Wool Exchange, Coleman Street, London, E.C.)
1877. Carter, William, Manager, The Hydraulic Engineering Company, Chester.

1888. Castle, Frank, Royal College of Science, Exhibition Road, South Kensington, London, S.W.

1891. Caswell, Samuel John, 31 Sakai Machi, Kobe, Japan.

1892. Causer, William George, Brighton Villa, Handsworth, R.O., Birmingham.

1883. Cawley, George, 29 Great George Street, Westminster, S.W.

1892. Chadwick, Osbert, C. M. G., Crown Agents' Department, Colonial Office, Downing Street, London, S.W.; and 11 Airlie Gardens, Kensington, London, W.

1894. Chaffey, George, Messrs. Chaffey Brothers, 35 Queen Victoria Street, London, E.C.

1876. Challen, Stephen William, Messrs. Taylor and Challen. Derwent Foundry, 60 and 62 Constitution Hill, Birmingham. [*Derwent, Birmingham.*]

1892. Chalmers, George, St. John del Rey Mining Co., 28 Tower Chambers, Finsbury Pavement, London, E.C.

1886. Chalmers, John Reid, 18 Hemingford Road, Barnsbury, London, N.

1890. Chandler, Noel, Cannock Chase Foundry and Engine Works, Hednesford, near Stafford.

1887. Chapman, Alfred Crawhall, 3 St. Nicholas' Buildings, Newcastle-on-Tyne.

1888. Chapman, Arthur, Assam Railways and Trading Co., 1 Clive Ghat Street, Calcutta, India; The New Club, Calcutta, India: (or St. Andrew's Cottage, Bury St. Edmund's.)

1866. Chapman, Henry, 69 Victoria Street, Westminster, S.W. [*Tubalcain, London.*]; and 10 Rue Laffitte, Paris.

1878. Chapman, James Gregson, Messrs. Fawcett Preston and Co., Phœnix Foundry, Liverpool; and 25 Austinfriars, London, E.C. [*Fawcett, London.*]

1887. Chapman, Joseph Crawhall, 70 Chancery Lane, London, W.C.; and St. Mildred's, Lovelace Gardens, Surbiton.

1893. Charlesworth, Sheard, Messrs. S. Charlesworth and Co., Richmond Hill Iron Works, Oldham. [*Charlesworth, Engineers, Oldham.* 63.]

1885. Charnock, George Frederick, Engineering Department, Technical College, Bradford.

1895. Charnock, James, Messrs. Vikoul Morosoff and Sons, Orehovo, near Moscow, Russia: (or care of Messrs. Samuel Montagu and Co., 60 Old Broad Street, London, E.C.)

1877. Chater, John, Messrs. Henry Pooley and Son, 89 Fleet Street, London, E.C.

1890. Chater, John Richard, Madras Railway. Madras, India; and care of John Chater, 223 Peckham Rye, London, S.E.

1891. Chatterton, Alfred, Professor of Engineering, College of Engineering, Madras, India.

1887. Chatwin, James, Victoria Works, Great Tindal Street, Ladywood, Birmingham.

1867. Chatwood, Samuel, Lancashire Safe and Lock Works, Bolton; and High Lawn, Broad Oak Park, Worsley, near Manchester.

1873. Cheesman, William Talbot, Hartlepool Rope Works, Hartlepool.

1881. Chilcott, William Winsland, The Terrace, H.M. Dockyard, Sheerness.

1895. Chittenden, Edmund Barrow, West Malling, Kent.

1880. Churchward, George Dundas, Locomotive Superintendent, Imperial Chinese Railways, care of H.B.M.'s Consulate, Tientsin, North China: (or care of A. W. Churchward, London Chatham and Dover Railway, Queenborough Pier, Queenborough.)

1894. Churchward, George Jackson, Great Western Railway Carriage Works, Swindon.

1891. Clark, Augustus, Bowman's Heirs, Pernambuco, Brazil.

1871. Clark, Christopher Fisher, Mining Engineer, Garswood Coal and Iron Co., Park Lane Collieries, Wigan; and Cranbury Lodge, Park Lane, Wigan. [*Park Lane, Wigan.*]

1878. Clark, Daniel Kinnear, 8 Buckingham Street, Adelphi, London, W.C.

1867. Clark, George, Southwick Engine Works, near Sunderland.

1889. Clark, Thomas Alexander, Superintendent of Workshops, George Heriot's Hospital School, Edinburgh.

1885. Clarke, Leslie, 132 Westbourne Terrace, Hyde Park, London, W.

1894. Clarkson, Charles, Portland Harbour Torpedo Works, Weymouth.

1891. Clarkson, Thomas, Grove Villa, Carshalton Grove, Sutton, Surrey.

1892. Clay, Charles Butler, National Telephone Co., St. Andrew's House, Holborn Circus, London, E.C.

1882. Clayton, William Wikeley, Messrs. Hudswell Clarke and Co., Railway Foundry, Jack Lane, Leeds. [*Loco, Leeds.* 504.]

1890. Cleathero, Edward Thomas, Messrs. Cleathero and Nichols, Phœnix Works, Boleyn Road, Kingsland, London, N.; and 16 Tollington Place, London, N.

1890. Cleaver, Arthur, Engineer, Nottingham Laundry Co., Sherwood, near Nottingham; and Hornby House, Sherwood, near Nottingham.

1890. Cleland, William, Sheffield Testing Works, Blonk Street, Sheffield.

1871. Cleminson, James, Dashwood House, 9 New Broad Street, London, E.C. [*Catamarca, London.*]

1873. Clench, Frederick, Lincoln Works, Chesterfield.

1885. Clifton, George Bellamy, Great Western Railway Electric Light Works, 150 Westbourne Terrace, Paddington, London, W.

1885. Close, John, Jun., York Engineering Works, Leeman Road, York.

1885. Clutterbuck, Herbert, Engineers' Department, London County Council, Spring Gardens, London, S.W.

1882. Coates, Joseph, 117 Cannon Street, London, E.C.

1881. Cochrane, Brodie, Mining Engineer, Aldin Grange, Durham.

1858. Cochrane, Charles, Woodside Iron Works, near Dudley; and Green Royde, Pedmore, near Stourbridge.

1887. Cochrane, George, Resident Engineer, London Hydraulic Power Works, 46 Holland Street, Blackfriars Road, London, S.E.

1885. Cochrane, John, Grahamston Foundry and Engine Works, Barrhead, near Glasgow. [*Cochrane, Barrhead.*]

1869. Cochrane, Joseph Bramah, Woodside Iron Works, near Dudley.

1868. Cochrane, William, Mining Engineer, Elswick Colliery, Elswick, Newcastle-on-Tyne; and Oakfield House, Gosforth, Newcastle-on-Tyne.

1864. Coddington, William, M.P., Ordnance Cotton Mill, Blackburn; and Wycollar, Blackburn.

1889. Coey, Robert, Assistant Locomotive Engineer, Great Southern and Western Railway, Inchicore Works, near Dublin.

1889. Colam, William Newby, Billiter Buildings, Billiter Street, London, E.C. [*Colam, London.*]

1892. Cole, Henry Aylwin Bevan, 79½ Gracechurch Street, London, E.C. [*Carbuncle, London.*]

1878. Coles, Henry James, Sumner Street, Southwark, London, S.E.

1884. Collenette, Ralph, Fairfield House, Idle, near Bradford.

1884. Coltman, John Charles, Messrs. Huram Coltman and Son, Engineering Works, Meadow Lane, Loughborough.

1878. Colyer, Frederick, 18 Great George Street, Westminster, S.W.

1888. Combe, Abram, Messrs. Combe Barbour and Combe, Falls Foundry, Belfast.

1889. Common, John Freeland Fergus, 4 Bute Crescent, Cardiff.

1881. Compton-Bracebridge, John Edward, Messrs. Easton Anderson and Goolden, 3 Whitehall Place, London, S.W.

1888. Constantine, Ezekiel Grayson, 32 Victoria Street, Manchester. [*Constant, Manchester.*]

1886. Conyers, Sidney Ward, Railway Construction Branch, Public Works Department, Sydney, New South Wales.

1874. Conyers, William, Albury, New South Wales.

1888. Cook, John Joseph, Messrs. Robinson Cooks and Co., Atlas Foundry, St. Helen's, Lancashire.

1892. Cooke, Rupert Thomas, 51 Angus Street, Roath, Cardiff.

1877. Cooper, Arthur, North Eastern Steel Co., Royal Exchange, Middlesbrough.

1883. Cooper, Charles Friend, Messrs. Paterson and Cooper, 68 Victoria Street, Westminster, S.W. [*Patella, London.* 1140.]

1877. Cooper, George, Pencliffe, Alleyne Road, West Dulwich, London, S.E.

1891. Cooper, Myles, 36 Victoria Street, Manchester.

1874. Cooper, William, Neptune Engine Works, Hull. [*Neptune, Hull.*]

1881. Coote, Arthur, Messrs. R. and W. Hawthorn Leslie and Co., Hebburn, Newcastle-on-Tyne.

1885. Coppée, Evence, 223 Avenue Louise, Bruxelles, Belgium.

1892. Corin, Philip Burne, Messrs. J. M. B. Corin and Son, Anchor Foundry Penzance.

1895. Corner, John Frederick, Boiler Insurance and Steam Power Co., 67 King Street, Manchester.

1895. Cornish, Edwin, Chief Engineer, R.N., H.M.S. "Brilliant," Chatham.

1848. Corry, Edward (*Life Member*), 9 New Broad Street, London, E.C.

1881. Cosser, Thomas, McLeod Road Iron Works, Kurrachee, India: (or care of Messrs. Ironside Gyles and Co., 1 Gresham Buildings, Guildhall, London, E.C.)

1883. Cotton, Henry Streatfeild, London Hydraulic Power Co., Palace Chambers, Bridge Street, Westminster, S.W.

1894. Cottrill, John Ormerod, Bee Hive Works, Bolton.

1887. Coulman, John, Hull and Barnsley Railway, Spring Head Works, Hull.

1895. Couper, Sinclair, Messrs. Lindsay Burnet and Co., Moore Park Boiler Works, Govan, Glasgow. [*Burnet, Glasgow.* 1513.]

1878. Courtney, Frank Stuart, Messrs. Easton Anderson and Goolden, 3 Whitehall Place, London, S.W.; and 76 Redcliffe Square, South Kensington, London, S.W.

1875. Coward, Edward, Messrs. Melland and Coward, Cotton Mills and Bleach Works, Heaton Mersey, near Manchester.

1875. Cowen, Edward Samuel, Messrs. G. R. Cowen and Co., Beck Works, Brook Street, Nottingham; and 9 The Ropewalk, Nottingham. [*Cowen, Nottingham.* 87.]

1880. Cowper, Charles Edward, 6 Great George Street, Westminster, S.W.

1892. Cowper-Coles, Sherard Osborn, 39 Victoria Street, Westminster, S.W.; and 16 Adam Street, Manchester Square, London, W.

1878. Coxhead, Frederick Carley, 27 Leadenhall Street, London, E.C.

1866. Craven, William, Messrs. Craven Brothers, Vauxhall Iron Works, Osborne Street, Manchester. [*Vauxhall, Manchester.* 659.]

1894. Craven, William H. S., Messrs. Craven Brothers, Vauxhall Iron Works, Osborne Street, Manchester. [*Vauxhall, Manchester.* 659.]

1889. Cribb, Frederick James, Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough.

1884. Crighton, John, Messrs. Crighton and Co., 20 Exchange Buildings, St. Mary's Gate, Manchester. [*Vacuum, Manchester.*]

1893. Crippin, Thomas Henry, Bolton Engineering Co., Turton Street, Bolton; and 89 Bury New Road, Bolton.

1883. Croft, Henry, M.P., Chemanns, Vancouver Island.

1878. Crohn, Frederick William, 14 Burney Street, Greenwich, London, S.E.

1877. Crompton, Rookes Evelyn Bell, Arc Works, Chelmsford; and Mansion House Buildings, Queen Victoria Street, London, E.C. [*Crompton, Chelmsford.*]

1884. Crook, Charles Alexander, Telegraph Construction and Maintenance Works, Enderby's Wharf, East Greenwich, London, S.E.

1881. Crosland, James Foyell Lovelock, Chief Engineer, Boiler Insurance and Steam Power Co., 67 King Street, Manchester.

1891. Crosland, Joseph, Messrs. Seebohm and Dieckstahl, Dannemora Steel Works, Sheffield; and Stanley Avenue, Birkdale, Southport.

1875. Crossley, William John, Messrs. Crossley Brothers, Great Marlborough Street, Manchester. [*Crossleys, Openshaw.*]

1882. Cruickshank, William Douglass, Chief Government Engineer Surveyor, Marine Board, Sydney, New South Wales.

1889. Cullen, William Hart, Resident Engineer, The Aluminium Co., Oldbury, near Birmingham.

1887. Cutler, George Benjamin, Messrs. Samuel Cutler and Sons, Providence Iron Works, Millwall, London, E.; and 4 Westcombe Park, Blackheath, London, S.E.

1876. Cutler, Samuel, Messrs. Samuel Cutler and Sons, Providence Iron Works, Millwall, London, E. [*Cutler, Millwall.* 5059.]; and 16 Great George Street, Westminster, S.W.

1888. Dadabhoy, Cursetjee, Messrs. Shapurji Sorabji and Co., Bombay Foundry and Engine Works, Khetwady, Bombay, India; and Cumbala Hill, Bombay, India.

1864. Daglish, George Heaton, Rock Mount, St. Anne's Road, Aigburth, near Liverpool. [*Daglish, Aigburth.* 2717.]

1891. Daglish, Harry Bolton, Messrs. Robert Daglish and Co., St. Helen's Engine and Boiler Works, St. Helen's, Lancashire.

1895. Daintree, Thomas Ekins, Messrs. Tangyes, P.O. Box 818, Johannesburg, Transvaal, South Africa.

1883. D'Albert, Charles, Société des Anciens Établissements Hotchkiss et Cie., 6 Route de Gonesse, St. Denis, Seine, France.

1890. Dalby, William Ernest, Engineering Department, The University, Cambridge.

1889. Dalgarno, James Robert, Danesford, Countess Wells Road, Mannofield, Aberdeen.

1893. Dall, John, Messrs. Harland and Wolff, Belfast.

1893. Dalrymple, Alexander, Superintendent Engineer, Hall Line of Steamers, 19 Tower Buildings N., Water Street, Liverpool.

1881. D'Alton, Patrick Walter, London Electric Supply Corporation, Stowage Wharf, Deptford, London, S.E.

1866. Daniel, Edward Freer, Messrs. Worthington and Co., The Brewery, Burton-on-Trent; and 89 Derby Street, Burton-on-Trent.

1866. Daniel, William, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds; and Fern Bank, Horsforth, Leeds.

1891. Daniels, Thomas, Messrs. Nasmyth Wilson and Co., Patricroft, Manchester.

1888. Darbishire, James Edward, 110 Cannon Street, London, E.C. [*Ezra, London.* 11306.]

1878. Darwin, Horace (*Life Member*), The Orchard, Huntingdon Road, Cambridge.

1873. Davey, Henry, Messrs. Hathorn Davey and Co., Sun Foundry, Dewsbury Road, Leeds [*Sun Foundry, Leeds*]; and 3 Prince's Street, Westminster, S.W. [*Subterranean, London.*]

1888. Davidson, Samuel Cleland, Sirocco Works, Bridge End, Belfast.

1880. Davies, Charles Merson, Messrs. Dübs and Co., Glasgow Locomotive Works, Glasgow; and Laurieville, Queen's Drive, Crosshill, Glasgow.

1885. Davies, Edward John Mines, 24 Harrington Square, London, N.W.

1891. Davies, John Hubert, P.O. Box 455, Johannesburg, Transvaal, South Africa.

1894. Davis, George, Engineer's Office, Lancashire and Yorkshire Railway, Hunt's Bank, Manchester.

1868. Davis, Henry Wheeler, 5 Highbury Grove, Highbury, London, N.

1877. Davison, John Walter, Bombay Baroda and Central India Railway, Ahmedabad, India: (or care of Mrs. Channon, 23 Streatley Road, Brondesbury, London, N.W.)

1884. Davison, Robert, Locomotive Department, Caledonian Railway, St. Rollox, Glasgow.

1873. Davy, David, Messrs. Davy Brothers, Park Iron Works, Sheffield. [*Motor, Sheffield.*]

1892. Davy, William James, 15 Victoria Street, Westminster, S.W.

1883. Daw, James Gilbert, Messrs. Nevill Druce and Co., Llanelly Copper Works, Llanelly.

1874. Daw, Samuel, 50 Chelsea Road, Southsea, Portsmouth.

1879. Dawson, Bernard, 110 Cannon Street, London, E.C. [*Crocus, London.*] and The Laurels, Malvern Link, Malvern. [*Heather, Malvern Link.*]

1875. Dawson, Edward, 2 Windsor Place, Cardiff. [*Mechanical, Cardiff.*]

1890. Day, George Cameron, Messrs. Day Summers and Co., Northam Iron Works, Southampton.

1886. Dayson, William Ogden, Blaenavon Works, Blaenavon, R.S.O., Monmouthshire.

1874. Deacon, George Frederick, 32 Victoria Street, Westminster, S.W.

1880. Deacon, Richard William, Boeboetan, Battenhall Road, Worcester.

1894. Deakin, Benjamin Walter, Resident Engineer, City of London Electric Lighting Station, 64 Bankside, Southwark, London, S.E.; and 4 Farm Avenue, Streatham, London, S.W.

1868. Dean, William, Locomotive Superintendent, Great Western Railway, Swindon.

1887. Deas, James, Clyde Navigation, Glasgow.

1866. Death, Ephraim, Messrs. Death and Ellwood, Albert Works, Leicester.

1884. Decauville, Paul, Portable Railway Works, Petit Bourg, Seine-et-Oise, France. [*Decauville, Corbeil.*]

1890. Deeley, Richard Mountford, Locomotive Department, Midland Railway, Derby; and 10 Charnwood Street, Derby.

1877. Dees, James Gibson, 36 King Street, Whitehaven.

1889. Defries, Wolf, Messrs. Defries and Sons, 147 Houndsditch, London, E. [*Defries, London.*]

1882. Denison, Samuel, Messrs. Samuel Denison and Son, Old Grammar School Foundry, North Street, Leeds. [*Weigh, Leeds.* 221.]

1892. Dennis, George D., Superintendent Engineer to William Whiteley, 147 Queen's Road, London, W.

1888. Dent, Charles Hastings, London and North Western Railway, Lime Street Station, Liverpool.

1895. Dewhurst, John Henry, Messrs. John Dewhurst and Son, Attercliffe Road, Sheffield. [1614.]

1883. Dick, Frank Wesley, Palmers Shipbuilding and Iron Works, Jarrow.

1891. Dick, John Norman, Government Marine Surveyor, Penang, Straits Settlements.

1890. Dickinson, Alfred, Engineer, South Staffordshire Tramways, Darlaston, Wednesbury.

1891. Dickinson, James Clark, Palmer's Hill Engine Works, Sunderland.

1880. Dickinson, John, Palmer's Hill Engine Works, Sunderland. [*Bede, Sunderland.*]

1892. Dickinson, Richard Elihu, Bowling Iron Works, Bradford.

1892. Dickinson, Richard Henry, Locomotive Superintendent, Birmingham Central Tramways, Kyotts Lake Depôt, Birmingham.

1875. Dickinson, William, Warham Road, Croydon.

1888. Dickson, George Manners, Assistant Engineer, Calcutta Water Works, Municipal Office, Calcutta, India.

1886. Dixon, Robert, 4 Tyne Vale Terrace, Gateshead.

1883. Dixon, Samuel, Messrs. Kendall and Gent, Victoria Works, Springfield, Salford, Manchester. [*Tools, Manchester.* Nat. 330; Mutual 1330.]

1887. Dixon, William Basil, 18 Westcott Street, Hull.

1872. Dobson, Benjamin Alfred, Messrs. Dobson and Barlow, Kay Street Machine Works, Bolton. [*Dobsons, Bolton.*]

1873. Dobson, Richard Joseph Caistor, De Volharding, Soerabaya, Java: (or care of Miss Dobson, 4 Chesterfield Buildings, Victoria Park, Clifton, Bristol.)

1880. Dodd, John, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1868. Dodman, Alfred, Highgate Foundry, Lynn. [*Dodman, Lynn.*]

1889. Dolby, Ernest Richard, 8 Prince's Street, Westminster, S.W.

1880. Donald, James, Superintendent Engineer, Messrs. James Fisher and Sons, Fisher's Buildings, Barrow-in-Furness.

1876. Donaldson, John, Messrs. John I. Thornycroft and Co., Steam Yacht and Launch Builders, Church Wharf, Chiswick, London, W.; and Tower House, Turnham Green.

1873. Donkin, Bryan (*Life Member*), Messrs. Bryan Donkin and Co., 55 Southwark Park Road, Bermondsey, London, S.E. [*Donkin Company, London.* 4662.]; and The Mount, Wray Park, Reigate.

1895. Donkin, Harry Julyan, Works Manager, Messrs. Bryan Donkin and Co., 55 Southwark Park Road, Bermondsey, London, S.E.

1891. Donovan, Edward Wynne, Messrs. J. S. Leach and Co., Mount Street Works, Harpurhey, Manchester.

1865. Douglas, Charles Prattman, Thornbeck Hill, Carmel Road, Darlington.

1879. Douglass, Sir James Nicholas, F.R.S., Stella House, Dulwich, London, S.E.

1879. Douglass, William, Chief Engineer to the Commissioners of Irish Lights, Westmoreland Street, Dublin.

1891. Douglass, William James, Messrs. Douglass Brothers, Globe Iron Works, Blaydon-on-Tyne, R.S.O., County Durham.

1887. Douglass, William Tregarthen, 15 Victoria Street, Westminster, S.W.

1857. Dove, George, Messrs. Cowans Sheldon and Co., St. Nicholas Engine and Iron Works, Carlisle; and Viewfield, Stanwix, near Carlisle.

1873. Dove, George, Redbourn Hill Iron and Coal Co., Frodingham, near Doncaster [*Redbourn, Frodingham.*]; and Hatfield House, Hatfield, near Doncaster.

1866. Downey, Alfred C., Messrs. Downey and Co., Coatham Iron Works, Middlesbrough; and Belle Vue, Marton Road, Middlesbrough.

1881. Dowson, Joseph Emerson, 39 Old Queen Street, Westminster, S.W. [*Gaseous, London.*]

1880. Doxford, Robert Pile, Messrs. William Doxford and Sons, Pallion Shipbuilding and Engine Works, Sunderland.

1874. Dredge, James, 35 Bedford Street, Strand, London, W.C. [3663.]

1890. Drewet, Tom, Government Senior Inspector of Steam Boilers, Town Custom House, Bombay, India.

1886. Drummond, Dugald, Messrs. D. Drummond and Son, Glasgow Railway Engineering Works, Helen Street, Govan, Glasgow. [*Expansion, Glasgow.* 1699.]

1889. Drummond, Richard Oliver Gardner, P. O. Box 92, Johannesburg, Transvaal, South Africa.

1877. Dübs, Charles Ralph, Messrs. Dübs and Co., Glasgow Locomotive Works, Glasgow.

1885. Duckering, Charles, Water Side Works, Rosemary Lane, Lincoln.

1880. Duckham, Frederic Eliot, Engineer, Millwall Docks, London, E.

1868. Dugard, William Henry, Messrs. Dugard Brothers, Vulcan Rolling Mills, Bridge Street West, Summer Lane, Birmingham. [*Vulcan, Birmingham.*]

1879. Duncan, David John Russell, care of Messrs. Neish, Howell and Macfarlane, 66 Watling Street, London, E.C.

1886. Duncan, Norman, Mechanical Engineer to the Municipality, Rangoon, British Burmah, India.

1894. Dunell, George Robert, 36 Bedford Street, Strand, London, W.C.; and 9 Grove Park Terrace, Chiswick, London, W.

1892. Dunlop, James, Victoria Jubilee Technical Institute, Byculla, Bombay, India.

1870. Dunlop, James Wilkie, 39 Delancey Street, Regent's Park, London, N.W.

1890. Dunn, Hugh Shaw, Engineer, Caprington Collieries, Kilmarnock.

1885. Durham, Frederick William, 27 Leadenhall Street, London, E.C. [*Oilring, London.*]; and Glemham Lodge, New Barnet.

1886. Duvall, Charles Anthony, Messrs. E. Bennis and Co., Lancashire Stoker Works, Deansgate Foundry, Bolton.

1887. Dymond, George Cecil, Messrs. W. P. Thompson and Co., 6 Lord Street, Liverpool.

1865. Dyson, Robert, Messrs. Owen and Dyson, Rother Iron Works, Rotherham.

1880. Eager, John Edward, Messrs. William Crichton and Co., Engineering and Shipbuilding Works, Abo, Finland.

1869. Earnshaw, William Lawrence, Superintending Marine Engineer, South Eastern Railway, Folkestone.

1858. Easton, Edward, 11 Delahay Street, Westminster, S.W.
1884. Eastwood, Charles, Manager, Linacre Gas Works, Liverpool.
1892. Eastwood, Thomas Carline, Messrs. Eastwood Swingler and Co., Victoria and Railway Iron Works, Derby. [*Swingler, Derby.*]
1888. Eaton-Shore, George, Borough Engineer, Temple Chambers, Crewe.
1875. Eaves, William, Engineer, Messrs. John Brown and Co., Atlas Steel and Iron Works, Sheffield.
1878. Eckart, William Roberts, Messrs. Salkeld and Eckart, 632 Market Street, P. O. Box 1844, San Francisco, California, United States.
1868. Eddison, Robert William, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.
1886. Ede, Francis Joseph, Messrs. Ede Brothers, Silchar, Cachar, India.
1893. Eden, The Hon. Francis Fleetwood, Los Talleres de Sola, Ferro Carril del Sud, Buenos Aires, Argentine Republic: (or Edenthorpe, Doncaster.)
1887. Edlin, Herbert William, P.O. Box 674, Johannesburg, Transvaal, South Africa. [*Motor, Johannesburg.*]
1883. Edmiston, James Brown, Marine Superintending Engineer, Messrs. Hamilton Fraser and Co., K Exchange Buildings, Liverpool; and Ivy Cottage, Highfield Road, Walton, Liverpool.
1877. Edwards, Frederick, 62 Bishopsgate Street Within, London, E.C.
1885. Edwards, Walter Cleeve, Vryburg, British Bechuanaland, South Africa.
1888. Ellery, Henry George, 7 Fernbank Road, Redland, Bristol.
1875. Ellington, Edward Bayzand, Hydraulic Engineering Works, Chester; and Hydraulic Engineering Co., Palace Chambers, 9 Bridge Street, Westminster, S.W.
1892. Elliott, Archibald Campbell, D.Sc., Professor of Engineering, University College of South Wales and Monmouthshire, Cardiff.
1895. Elliott, George, 10 Oceanic Avenue, Belfast.
1883. Elliott, Henry John, Assistant Manager, Elliott's Metal Works, Selly Oak, near Birmingham. [*Elmeco, Birmingham.*]
1882. Elliott, Thomas Graham, Messrs. Fairbairn Naylor Macpherson and Co., Wellington Foundry, Leeds.
1895. Ellis, Arthur Devonshire, Managing Director, Messrs. Thwaites Brothers, Vulcan Iron Works, Bradford.
1892. Ellis, Joseph S., Central Engineering Works, Chepstow [*Engineer, Chepstow.*]; and Myrtle Cottage, Chepstow.
1880. Ellis, Oswald William, 6 Grosvenor Place, Jesmond, Newcastle-on-Tyne. [*Robey, Newcastle-on-Tyne.*]
1885. Elsworthy, Edward Houtson, Messrs. Richardson and Cruddas, Byculla Iron Works, Bombay, India; and Altamont Road, Cumbala Hill, Bombay, India.

1875. Elwell, Thomas, 223 Avenue de Paris, Plaine St. Denis, Seine, France.

1878. Elwin, Charles, London County Council, Spring Gardens, London, S.W.

1890. English, Lt.-Colonel Thomas, Hawley, near Dartford.

1894. English, Thomas Matthew, Superintendent, Die and Coining Department, H. M. Mint, Bombay, India.

1894. Ennor, Charles John, 55 Rua da Reboleira, Oporto, Portugal.

1890. Esson, John, Chatteris Engineering Works, Chatteris, S.O., Cambridgeshire.

1889. Etches, Harry, 17 Napoleon Street, Brantford, Ontario, Canada.

1884. Etherington, John, 39A King William Street, London Bridge, London, E.C.

1887. Evans, Arthur George, Palace Chambers, 9 Bridge Street, Westminster, S.W.

1884. Evans, David, Messrs. Bolckow Vaughan and Co., Cleveland Iron and Steel Works, South Bank, R.S.O., Yorkshire.

1892. Evanson, Frederic Macdonnell, Hazelhurst, Urmston, near Manchester.

1887. Everard, John Breedon, 6 Millstone Lane, Leicester.

1887. Everitt, Nevill Henry, Messrs. Thomas Piggott and Co., Atlas Works, Birmingham; and Hillside, Knowle, Warwickshire.

1881. Ewen, Thomas Buttwell, Messrs. Ewen and Mitton, Smithfield Works, Sherlock Street, Birmingham.

1891. Ewing, James Alfred, F.R.S., Professor of Mechanism and Applied Mechanics, Engineering Department, The University, Cambridge; and Langdale Lodge, Cambridge.

1890. Exton, George Gaskell, Messrs. Chubb and Son, 128 Queen Victoria Street, London, E.C.

1868. Fairbairn, Sir Andrew, Messrs. Fairbairn Naylor Macpherson and Co., Wellington Foundry, Leeds; and Askham Richard, York.

1875. Farcot, Jean Joseph Léon, Messrs. Farcot and Sons, Engine Works, 13 Avenue de la Gare, St. Ouen, France.

1880. Farcot, Paul, Messrs. Farcot and Sons, Engine Works, 13 Avenue de la Gare, St. Ouen, France.

1881. Farrar, Sidney Howard, Messrs. Howard Farrar and Co., Port Elizabeth, South Africa; and care of Messrs. F. A. Robinson and Co., 54 Old Broad Street, London, E.C.

1882. Fawcett, Thomas Constantine, White House Engineering Works, Leeds. [*Fawcett, Leeds.*]

1882. Feeny, Victor Isidore, 60 Queen Victoria Street, London, E.C. [*Victor Feeny, London.*]

1876. Fell, John Corry, 1 Queen Victoria Street, London, E.C.; and Excelsior Works, Old Street, London, E.C.
1869. Fenwick, Clennell, Victoria Docks Engine Works, Victoria Docks, London, E. [*Clennell, London.*]
1892. Fenwick, James, 19 Bridge Street, Sydney, New South Wales. [1038.]
1870. Ferguson, Henry Tanner, Wolleigh, Bovey Tracey, near Newton Abbot.
1881. Ferguson, William, Harbour Board, Wellington, New Zealand: (or care of Montgomery Ferguson, 81 James Street, Dublin.)
1866. Fiddes, Walter, Clapton Villa, Belgrave Road, Tyndall's Park, Bristol.
1867. Field, Edward, 4 Trafalgar Square, London, W.C.
1888. Field, Howard, 12 London Street, Fenchurch Street, London, E.C.
1884. Fielden, Joseph Petrie, Messrs. Thomas Robinson and Son, Railway Works, Rochdale.
1874. Fielding, John, Messrs. Fielding and Platt, Atlas Iron Works, Gloucester. [*Atlas, Gloucester.*]
1891. Finlayson, Finlay, East End Villa, Lugar Street, Coatbridge.
1891. Firth, George Henry, 2 Mavesyn Place, Fairfield, Manchester.
1888. Fischer, Gustave Joseph, Railway Construction Branch, Public Works Department, Sydney, New South Wales; and Oakhurst, West Street, North Sydney, New South Wales.
1889. Fisher, Henry Bedwell, Marine Shops, London Brighton and South Coast Railway, Newhaven, Sussex.
1884. Fisher, Henry Oakden, Ty Mynydd, Radyr, near Cardiff.
1888. FitzGerald, Maurice Frederick, Professor of Engineering, Queen's College, Belfast.
1877. Flannery, James Fortescue, M.P., 9 Fenchurch Street, London, E.C. [2283.]
1883. Fletcher, George, Masson and Atlas Works, Litchurch, Derby.
1872. Fletcher, Herbert, Ladyshore Colliery, Little Lever, Bolton; and The Hollins, Bolton.
1867. Fletcher, Lavington Evans, Chief Engineer, Manchester Steam Users' Association, 9 Mount Street, Albert Square, Manchester. [*Steam Users', Manchester.*]
1892. Focken, Charles Frederick, Messrs. Apcar and Co., Raddah Bazar, Calcutta, India; and care of Institute of Engineers and Shipbuilders, Hong Kong, China.
1859. Fogg, Robert, 159 Knight's Hill, West Norwood, London, S.E.
1887. Foley, Nelson, Engineering Manager, Società Industriale Napoletana Hawthorn-Guppy, Naples, Italy.
1877. Forbes, Daniel Walker, Smithfield Works, New Road, Blackwall, London, E.

1882. Forbes, David Moncur, Engineer, H. M. Mint, Bombay.

1892. Forbes, Percy Alexander, Messrs. Lambert Brothers, Tube Mills, Iron and Brass Works, Walsall.

1882. Forbes, William George Loudon Stuart, Mechanical Superintendent, H. M. Mint, Calcutta.

1892. Forrest, Hilary Sheldon, General Manager, Messrs. Dobson and Barlow, Kay Street Machine Works, Bolton.

1888. Forster, Alfred Llewellyn, Assistant Engineer, Newcastle and Gateshead Water Works, Newcastle-on-Tyne.

1888. Forster, Edward John, Malta Villa, West Smethwick, Birmingham.

1882. Forsyth, Robert Alexander, Courtway, Gold Tops, Newport, Monmouthshire.

1889. Foster, Ernest Howard, Messrs. Henry R. Worthington, 86 Liberty Street, New York, United States.

1889. Foster, Herbert Anderton (*Life Member*), Messrs. John Foster and Son, Black Dike Spinning Mills, Queensbury, near Bradford.

1888. Foster, James, Lily Bank, St. Andrew's Drive, Pollokshields, Glasgow.

1884. Foster, John Slater, Messrs. Jones and Foster, 39 Bloomsbury Street, Birmingham.

1882. Fothergill, John Reed, Consulting Engineer, Dock Office, West Hartlepool; and 1 Bathgate Terrace, West Hartlepool.

1877. Foulis, William, Manager, Glasgow Corporation Gas Department, City Chambers, 45 John Street, Glasgow.

1885. Fourny, Hector Foster, French Chambers, Queen's Dock-Side, Hull. [*Veritas, Hull.*]

1866. Fowler, George, Basford Hall, near Nottingham.

1847. Fowler, Sir John, Bart., K.C.M.G., 2 Queen Square Place, Westminster, S.W.

1894. Fowler, Robert Henry, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds. [*Fowler, Leeds.*]

1885. Fowler, William Henry, 6 Victoria Station Approach, Manchester; and Calderbank Avenue, Flixton, near Manchester.

1866. Fox, Sir Douglas, 28 Victoria Street, Westminster, S.W.

1875. Fox, Samson, Leeds Forge, Leeds.

1884. Frampton, Edwin, General Engine and Boiler Co., Hatcham Iron Works, Pomeroy Street, New Cross Road, London, S.E. [*Oxygen, London.* 8007.]

1885. Franki, James Peter, Morts Dock and Engineering Co., Morts Bay, Sydney, New South Wales: (or care of Messrs. Goldsbrough Mort and Co., 149 Leadenhall Street, London, E.C.)

1877. Fraser, John Hazell, Messrs. John Fraser and Son, Millwall Boiler Works, London, E.; and 110 Cannon Street, London, E.C.

1888. Frenzel, Arthur Benjamin, 318 W. 135th Street, New York, United States.

1891. Frier, John Drummond, Ivy Villa, 6 Griffin Road, Plumstead.
1866. Fry, Albert, Bristol Wagon Works, Lawrence Hill, Bristol.
1891. Fuller, Charles Frederick, 171 Queen Victoria Street, London, E.C.
1884. Furness, Edward, Knollcroft, Knoll Road, Bexley, S.O., Kent.

1890. Gadd, William, Assistant Locomotive Engineer, Waterford and Limerick Railway, Limerick.
1866. Galloway, Charles John, Managing Director, Messrs. Galloways, Knott Mill Iron Works, Manchester. [*Galloway, Manchester.*]
1862. Galton, Sir Douglas, K.C.B., D.C.L., LL.D., F.R.S., 12 Chester Street, Grosvenor Place, London, S.W.
1884. Ganga Ram, Rai Bahadur, Executive Engineer, Public Works Department, Amritsar, Punjaub, India: (or care of Messrs. Thomas Wilson and Co., 24 Rood Lane, London, E.C.)
1891. Garrard, Charles Riley, Draycott Mills, Derbyshire. [*Chain, Draycott, Derby.*]
1882. Garrett, Frank, Messrs. Richard Garrett and Sons, Leiston Works, Leiston, R.S.O., Suffolk. [*Garrett, Leiston.*]
1894. Gatehouse, Tom Ernest, 22 Paternoster Row, London, E.C. [*Ageekay, London.*]
1867. Gauntlett, William Henry, 33 Albert Terrace, Middlesbrough. [*Pyrometer, Middlesbrough.*]
1895. Gaynor, Captain Henry Francis, R.E., School of Military Engineering, Chatham.
1888. Gaze, Edward Henry James, 4 Victoria Drive, Mount Florida, Glasgow.
1895. Geach, Frederick Samuel, Messrs. John Vipond and Co., Varteg Hill Colliery, near Pontypool.
1888. Geddes, Christopher, 2A Drury Buildings, Water Street, Liverpool. [*Graccius, Liverpool.*]
1880. Geoghegan, Samuel, Messrs. A. Guinness Son and Co., St. James' Gate Brewery, Dublin. [*Guinness, Dublin.*]
1887. Gibb, Andrew, Managing Engineer, Messrs. Rait and Gardiner, Millwall Docks, London, E.; and 30 South Street, Greenwich, London, S.E.
1871. Gibbins, Richard Cadbury, Berkley Street, Birmingham. [*Gibbins, Birmingham.*]
1883. Gilchrist, Percy Carlyle, F.R.S. (*Life Member*), Palace Chambers, 9 Bridge Street, Westminster, S.W. [*Gilchrist, London*]; and Frognal Bank, Finchley New Road, Hampstead, London, N.W.
1880. Gill, Charles, Messrs. Young and Gill, Engineering Works, Java; and Java Lodge, Beckenham.

1889. Gill, Frederick Henry, Messrs. Alexander Penney and Co., 107 Fenchurch Street, London, E.C.

1884. Gimson, Arthur James, Messrs. Gimson and Co., Engine Works, Vulcan Street, Leicester. [*Gimson, Leicester.* 6.]

1881. Girdwood, William Wallace, Indestructible Packing Works, 9 Lea Place, East India Dock Road, Poplar, London, E.

1874. Gjers, John, Messrs. Gjers Mills and Co., Ayresome Iron Works, Middlesbrough.

1887. Gledhill, Manassah, Sir Joseph Whitworth and Co., Openshaw, Manchester.

1880. Godfrey, William Bernard, 23 St. Swithin's Lane, London, E.C.

1888. Goff, John, Messrs. Salt and Co., The Brewery, Burton-on-Trent.

1882. Goldsmith, Alfred Joseph, Lillington, Moray Street, New Farm, Brisbane, Queensland.

1877. Goodbody, Robert, Messrs. Goodbody, Clashawaun Jute Factory, Clara, near Moate, Ireland.

1869. Goodeve, Thomas Minchin, 5 Crown Office Row, Temple, London, E.C.; and 38 Argyll Road, Kensington, London, W.

1875. Goodfellow, George Ben, Messrs. Goodfellow and Matthews, Hyde Iron Works, Hyde, near Manchester. [*Goodfellow, Hyde.*]

1890. Goodman, John, Professor of Engineering, Yorkshire College, Leeds.

1889. Goold, William Tom, Shillingford Works, Wallingford.

1865. Göransson, Göran Fredrick, Sandvik Iron Works, near Gefle, Sweden: (or care of James Bird, 118 Cannon Street, London, E.C.)

1887. Gordon, Alexander, Niles Tool Works, and Messrs. Gordon and Maxwell, Hamilton, Ohio, United States.

1879. Gorman, William Augustus, Messrs. Siebe and Gorman, 187 Westminster Bridge Road, London, S.E. [*Siebe, London.*]

1880. Gottschalk, Alexandre, 13 Rue Auber, Paris.

1877. Goulty, Wallis Rivers, Messrs. Wheatley Kirk, Price, and Goulty, Albert Chambers, Albert Square, Manchester. [*Indicator, Manchester.*]

1887. Gourlay, Charles Gershom, Messrs. Gourlay Brothers and Co., Dundee Foundry, Dundee.

1890. Grace, Robert William, Colorado Fuel and Iron Co., Pueblo, Colorado, United States.

1878. Grafton, Alexander, Vulcan Works, Bedford. [*Grafton, Bedford.*]

1886. Grant, Percy, Assistant Locomotive, Carriage, and Wagon Superintendent, Sola Works, Ferro Carril del Sud, Buenos Aires, Argentine Republic: (or care of John M. Grant, 136 Sutherland Avenue, Maida Vale, London, W.)

1895. Grant, Thomas Maxwell, Managing Director, Messrs. Napier Brothers, 100 Hyde Park Street, Glasgow. [*Windlass, Glasgow.* 714.]

1891. Gray, George Macfarlane (*Life Member*), care of J. Macfarlane Gray, 79 Mark Lane, London, E.C.

1865. Gray, John Macfarlane, Chief Examiner of Engineers, Marine Department, Board of Trade, 79 Mark Lane, London, E.C.; and 4 Ladbroke Crescent, Notting Hill, London, W. [*Yarg, London.*]

1876. Gray, John William, Engineer, Corporation Water Works, Broad Street, Birmingham.

1879. Gray, Thomas Lowe, Lloyd's Register, 2 White Lion Court, Cornhill, London, E.C.; and 24 St. Michael's Road, Stockwell, London, S.W.

1879. Greathead, James Henry, 15 Victoria Street, Westminster, S.W.

1861. Green, Sir Edward, Bart., Messrs. E. Green and Son, Phœnix Works, Wakefield.

1888. Green, Henry Joseph Kersting, Messrs. Barry and Co., 5 Lyons Range, Calcutta, India; 29 Clive Street, Calcutta, India: (or care of Messrs. J. B. Barry and Son, 110 Cannon Street, London, E.C.)

1893. Green, William Penrose, Messrs. Thomas Green and Son, Smithfield Iron Works, Leeds.

1871. Greener, John Henry, 15 Walbrook, London, E.C.

1895. Greensmith, James Eades, General Manager, Portland Locomotive and Car Works, Portland, Maine, United States.

1878. Greenwood, Arthur, Messrs. Greenwood and Batley, Albion Works, Leeds.

1874. Greenwood, William Henry (*Life Member*), Birmingham Small Arms and Metal Co., Adderley Park Works, Birmingham.

1894. Gregory, Horace Mark, Messrs. Brown, Lenox and Co., 9 Martin's Lane, Cannon Street, London, E.C.

1879. Grenville, Robert Neville, Butleigh Court, Glastonbury.

1892. Gresham, Harry Edward, Messrs. Gresham and Craven, Craven Iron Works, Salford, Manchester. [*Brake, Manchester.* 613.]

1880. Gresham, James, Messrs. Gresham and Craven, Craven Iron Works, Salford, Manchester. [*Brake, Manchester.* 613.]

1883. Grew, Frederick, Halton, 90 Ritherdon Road, Upper Tooting, London, S.W.

1874. Grew, Nathaniel, Dashwood House, 9 New Broad Street, London, E.C.

1895. Griffith, Percy, 55 Parliament Street, Westminster, S.W.

1895. Griffiths, Harry Denis, P.O. Box 455, Johannesburg, Transvaal, South Africa.

1884. Griffiths, James E., Messrs. Griffiths and James, 2 Bute Crescent, Cardiff.

1873. Griffiths, John Alfred, Arthursleigh, Western Road, Parramatta, New South Wales: (or care of Thomas Griffiths, Alderley Edge, Manchester.)

1889. Grimshaw, James Walter, Resident Engineer, Harbours and Rivers Department, Sydney, New South Wales; and Australian Club, Sydney, New South Wales.

1891. Groom, Richard Alfred, Shropshire Works, Wellington, Salop.

1879. Grose, Arthur, Messrs. Grose Norman and Co., Reliance Works, Northampton.

1886. Grove, David, 24 Friedrich Strasse, Berlin.

1884. Gulland, James Ker, Diamond Drill Co., 8 Victoria Street, Westminster, S.W. [*Gulland, London.*]

1870. Gwynne, James Eglinton Anderson (*Life Member*), Brooke Street Works, Holborn, London, E.C. [*Gwynnegram, London.*]

1870. Gwynne, John, Hammersmith Iron Works, Hammersmith, London, W.; and 89 Cannon Street, London, E.C.

1888. Hadfield, Robert Abbott, Hecla Foundry Steel Works, Sheffield. [*Hadfield, Sheffield.*]

1894. Haigh, Noel Newall, Messrs. W. B. Haigh and Co., Globe Iron Works, Plane Street, Oldham.

1884. Hall, Albert Francis, George F. Blake Manufacturing Co., 111 Federal Street, Boston; and 3 Cordis Street, Charlestown, Boston, Massachusetts, United States.

1892. Hall, George Edward, Mechanical Superintendent, Lighting Department, Salford Corporation, Wilburn Street, Salford, Manchester.

1894. Hall, Henry Platt, Messrs. Platt Brothers and Co., Hartford New Works, Oldham.

1879. Hall, John Francis, Norbury, Pittsmoor, Sheffield.

1881. Hall, John Percy, Managing Director, Messrs. John Penn and Sons, Greenwich, London, S.E.

1882. Hall, John Willim, Ivy House, Bilston.

1890. Hall, Oscar Standring, Messrs. Robert Hall and Sons, Hope Foundry, Bury, Lancashire.

1874. Hall, Thomas Bernard, 119 Colmore Row, Birmingham; and Ingleside, Sandon Road, Edgbaston, Birmingham.

1871. Hall, William Silver, 9A Tsukiji, Tokyo, Japan: (or care of Messrs. Takata and Co., 88 Bishopsgate Street Within, London, E.C.)

1889. Hall-Brown, Ebenezer, Messrs. Hall-Brown Buttery and Co., Helen Street Engine Works, Govan, Glasgow. [*Triple, Glasgow.* 1843.]

1880. Hallett, John Harry, 123 Bute Street, Cardiff. [*Consulting, Cardiff.*]

1871. Halpin, Druitt, 17 Victoria Street, Westminster, S.W. [*Halpin, London.* 3075, care of Victoria Chambers Co.]

1895. Halstead, John Henry, Locomotive Superintendent, Ferro-Carril de Taltal, Taltal, Chili.

1894. Hamer, Walter, Messrs. Dobson and Barlow, Kay Street Machine Works, Bolton. [*Dobsons, Bolton.*]

1894. Hamilton, Robert, Superintendent Engineer, Khye Ho Foundry Co., Penang, Straits Settlements.

1875. Hammond, Walter John, The Grange, Knockholt, near Sevenoaks.

1886. Hanbury, John James, Edgeley, Walm Lane, Willesden Park, London, N.W.

1870. Hannah, Joseph Edward, Castle View, Carlisle.

1892. Hansell, Robert Blackwell, Tenth Street, Walbrook, Baltimore, Maryland, United States: (or care of James Hansell, 62 Jerningham Road, New Cross, London, S.E.)

1891. Harcourt, Otto Simon Henry, Clarence Iron Works, Leeds.

1894. Harding, James Cooper, Messrs. T. Richardson and Sons, Hartlepool Engine Works, Hartlepool.

1883. Harding, Thomas Walter, Tower Works, Leeds.

1874. Harding, William Bishop, IX Ker. Rakos utcza 5 ik. sz., 1sö. Emelet, Budapest, Hungary.

1881. Hardingham, George Gatton Melhuish, 191 Fleet Street, London, E.C. [*Hardingham, London.*]

1883. Hardy, John George, 13 Riemergasse, Stadt, Vienna.

1869. Harfield, William Horatio, Mansion House Buildings, Queen Victoria Street, London, E.C.

1887. Hargraves, Richard, 3 London Road, Blackburn.

1887. Hargreaves, John Henry, Messrs. Hick Hargreaves and Co., Soho Iron Works, Crook Street, Bolton.

1888. Harker, William, Messrs. Richard Schram and Co., 17A Great George Street, Westminster, S.W.

1888. Harland, Sir Edward James, Bart., M.P., Messrs. Harland and Wolff, Belfast; and Baroda House, Kensington Palace Gardens, London, W.

1894. Harmer, Oscar, Babcock and Wilcox Boiler Works, Kilbowie, Glasgow.

1891. Harris, Gordon, Messrs. Merryweather and Sons, Fire-Engine Works, Greenwich Road, London, S.E.

1879. Harris, Henry Graham, Messrs. Bramwell and Harris, 5 Great George Street, Westminster, S.W. [*Wellbram, London.* 3060.]

1873. Harris, Richard Henry, 63 Queen Victoria Street, London, E.C.; and Oak Hill, Surbiton, R.O., near Kingston-on-Thames.

1877. Harris, William Wallington, Messrs. A. M. Perkins and Son, 6 Seaford Street, Regent Square, London, W.C.; and 24 Alexandra Villas, Hornsey Park, London, N.

1885. Harrison, Frederick Henry, Lincoln Malleable Iron Works, Lincoln. [*Malleable, Lincoln.*]

1888. Harrison, George, 21 Hillsboro Road, East Dulwich, London, S.E.

1889. Harrison, Captain Gilbert Harwood, R.E., War Office, Whitehall, London, S.W.

1885. Harrison, Joseph, Royal College of Science, Exhibition Road, South Kensington, London, S.W.

1891. Harrison, Joseph Hutchinson, Messrs. Howson and Harrison, 2 Exchange Place, Middlesbrough; and Clifford Villa, Coatham, Redcar.

1887. Harrison, Thomas Henry, Messrs. Davey Paxman and Co., 78 Queen Victoria Street, London. E.C.

1894. Harrison, William John, Locomotive Superintendent, Cia. Paulista, Rio Claro, São Paulo, Brazil; and 44 Bournemouth Road, Folkestone.

1890. Harrison, William Robert, Messrs. Harrison, Bilton and Sharp, Bank Chambers, Land of Green Ginger, Hull.

1883. Hart, Frederick, 36 Prospect Street, Poughkeepsie, New York, United States.

1872. Hartnell, Wilson, Benson's Buildings, Park Row, Leeds.

1882. Harvey, Charles Randolph, Messrs. G. and A. Harvey, Albion Machine Works, Govan, near Glasgow.

1892. Harvey, Francis Haniel, Messrs. Harvey and Co., Hayle Foundry, Hayle, Cornwall.

1886. Harvey, John Boyd, North's Navigation Collieries, Tondû, near Bridgend, Glamorganshire.

1883. Harvey, Robert, 1 Palace Gate, London, W.

1878. Harwood, Robert, Soho Iron Works, Bolton.

1881. Haslam, Sir Alfred Seale, Union Foundry, Derby. [*Zero, Derby.*]

1885. Hatton, Robert James, Henley's Telegraph Works, North Woolwich, London, E.

1857. Haughton, S. Wilfred (*Life Member*), Greenbank, Carlow, Ireland.

1878. Haughton, Thomas, 110 Cannon Street, London, E.C. [*Haughnot, London.*]

1885. Haughton, Thomas James, East Africa; and care of Mrs. Haughton, Draycott, near Weston-super-Mare.

1892. Hawkins, Rupert Skelton, District Locomotive Superintendent, Indian Midland Railway, Jhansi, India.

1861. Hawkins, William Bailey, 39 Lombard Street, London, E.C.

1870. Hawksley, Charles, 30 Great George Street, Westminster, S.W.

1891. Hawksley, George William, Brightside Boiler and Engine Works, Savile Street East, Sheffield. [*Hawksley, Sheffield.* 337.]

1873. Hay, James A. C., Superintending Engineer and Constructor of Shipping to the War Department, Royal Arsenal, Woolwich.

1882. Hayes, Edward, Watling Works, Stony Stratford. [*Hayes, Stony Stratford.*]

1879. Hayes, John, 55 Steep Hill, Lincoln.

1880. Hayter, Harrison, 33 Great George Street, Westminster, S.W.

1885. Head, Archibald Potter, Messrs. Jeremiah Head and Son, 47 Victoria Street, Westminster, S.W. [*Principium, London.* 3237]; and Queen's Square, Middlesbrough.

1888. Head, Harold Ellershaw, 5 Ilchester Mansions, Kensington, London, W.

1869. Head, Jeremiah, Messrs. Jeremiah Head and Son, 47 Victoria Street, Westminster, S.W. [*Principium, London.* 3237.]; and Queen's Square, Middlesbrough.

1857. Healey, Edward Charles, 33 Norfolk Street, Strand, London, W.C.

1890. Heap, Ray Douglas Theodore, Messrs. Crompton and Co., 4 Mansion House Buildings, Queen Victoria Street, London, E.C.; and 21 Park Road, Wimbledon.

1872. Heap, William, 28 Chapel Street, Liverpool. [*Metal, Liverpool.* 809.]

1889. Heath, George Wilson, Messrs. Heath and Co., Observatory Works, Crayford, Kent.

1888. Heatly, Harry, Messrs. Heatly and Gresham, 7 Hastings Street, Calcutta, India [*Brake, Calcutta.*]: (or Ballygunge, West Hill Road, Wandsworth, London, S.W.)

1875. Heenan, Hammersley, Messrs. Heenan and Froude, Newton Heath Iron Works, near Manchester; and The Manor House, Wilmslow, near Manchester. [*Spherical, Newton Heath.*]

1895. Heinke, Edwin Harry Alfred, Locomotive Superintendent, La Guaira and Caracas Railway, Caracas, Venezuela: (or care of Miss F. Heinke, The College, Stoke Bishop, near Bristol.)

1879. Hele-Shaw, Henry Selby, Professor of Engineering, University College, Liverpool.

1869. Henderson, David Marr, Engineer-in-Chief, Imperial Maritime Customs Service of China, Shanghai, China.

1883. Henderson, John Baillie, Engineer to the Queensland Government, Water Supply Department, Brisbane, Queensland.

1891. Henderson, Thomas, 6 and 8 Trueman Street, Liverpool. [*Mechanical, Liverpool.* 2366.]

1883. Henderson, William, P.O. Box 1933, Johannesburg, Transvaal, South Africa.

1888. Henning, Gustavus Charles, 726 Temple Court, 5 Beekman Street, New York, United States.

1879. Henriques, Cecil Quixam, Messrs. John H. Wilson and Co., 6 Delahay Street, Westminster, S.W.

1875. Hepburn, George, Redcross Chambers, Redcross Street, Liverpool. [*Hepburn, Liverpool.*]

1891. Hepburn, Thomas, Officiating Chief Mechanical Engineer, Small Arms Ammunition Factory, Kirkee, Poona, India.

1892. Herbert, Alfred, Machine-Tool Works, Coventry. [*Lathe, Coventry.* 52.]

1893. Herbert, Charles, 35 Queen Victoria Street, London, E.C. [*Mancunian, London.*]

1893. Herbert, George Henry, Messrs. Richard Hornsby and Sons, 75A Queen Victoria Street, London, E.C.

1894. Herman, Benjamin Richard, Messrs. B. R. Herman and Co, McLeod Road, Karachi, India. [*Herman, Karachi.* 47.]

1884. Hernu, Arthur Henry, 69 Victoria Street, Westminster, S.W.

1894. Herriot, William Scott, 187 Osmaston Road, Derby.

1881. Hervey, Matthew Wilson, Assistant Engineer, West Middlesex Water Works, Hammersmith, London, W.

1879. Hesketh, Everard, Messrs. J. and E. Hall, Iron Works, Dartford. [*Hesketh, Dartford.*]

1872. Hewlett, Alfred, Haseley Manor, Warwick.

1887. Hibbert, George, Hibbert's Works, Bank Road, Gateshead.

1885. Hicken, Thomas, La Compañia Fabricantes Ingleses, 302 Calle Balcarce, Buenos Aires, Argentine Republic: (or care of Miss Hicken, Bourton, near Rugby.)

1894. Higginbottom, Lloyd, Messrs. Higginbottom and Mannock, Crown Iron Works, West Gorton, Manchester.

1879. Higson, Jacob, Mining Engineer, Crown Buildings, 18 Booth Street, Manchester.

1883. Hill, John Kershaw, Engineer and Manager, West Surrey Water Works, High Street, Walton-on-Thames.

1885. Hill, Robert Anderson, Royal Mint, Little Tower Hill, London, E.

1890. Hiller, Edward George, Chief Engineer, National Boiler Insurance Co., 22 St. Ann's Square, Manchester.

1882. Hiller, Henry, Consulting Engineer, National Boiler Insurance Co., 22 St. Ann's Square, Manchester; and Athelney, Stanley Road, Alexandra Park, Manchester.

1873. Hilton, Franklin, 15 Duke Street, Southport.

1887. Hindson, William, South Shore Engineering Works, Gateshead. [*Hindson, Gateshead.*]

1891. Hodge, Arthur, Belle Vue Terrace, St. Austell.

1891. Hodges, Frank Grattidge, Locomotive Department, Midland Railway, Burton-on-Trent.

1870. Hodges, Petronius, 101 Burngreave Road, Pitsmoor, Sheffield.

1880. Hodgson, Charles, Messrs. Saxby and Farmer, Railway Signal Works, Canterbury Road, Kilburn, London, N.W. [*Signalmen, London.* 7068.]

1889. Hodgson, George Herbert, Thornton Road, Bradford.

1892. Hodgson, Henry Edwin, Brookhouse Iron Works, Cleckheaton, S.O., Yorkshire.

1891. Hogarth, Thomas Oswald, Great Western Railway Works, Swindon.

1889. Hoggins, Alfred Farquharson, 3 Pope Road, Bromley, Kent.

1866. Holcroft, Thomas, Bilston Foundry, Bilston.

1886. Holden, James, Locomotive Superintendent, Great Eastern Railway, Stratford Works, London, E.

1895. Holgate, Charles Henzell, Messrs. Whitley Partners, Railway Works, Leeds; and Cardigan Villa, Grove Lane, Headingley, Leeds.

1884. Holland, Calvert Bernard, Hazel Villa, Thicket Road, Anerley, London, S.E.

1895. Holliday, John, Messrs. A. Guinness, Son and Co., St. James' Gate Brewery, Dublin.

1886. Hollis, Charles William, Nottingham Engineering Co., St. Alban's Works, Radford, Nottingham. [*Iron, Nottingham.* 1578.]

1885. Hollis, Henry William, Whitworth House, Spennymoor.

1891. Holman, Hugh Wilson, Messrs. E. J. Caiger and Co., 77 Billiter Buildings, Billiter Street, London, E.C. [*Caiger, London.*]

1892. Holmström, Carl Albert, care of Swedish and Norwegian Consulate, Shanghai, China: (or care of Mrs. Holmström, 20 Highview Road, Upper Norwood, London, S.E.)

1883. Holroyd, John, 133 Croxted Road, West Dulwich, London, S.E.

1873. Holt, Henry Percy, 22 Chancery Lane, London, W.C.

1890. Holt, Robert, Professor of Engineering, The People's Palace Technical Schools, Mile End Road, London, E.

1890. Holt, William Procter, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1888. Homan, Harold, Messrs. Homan and Rodgers, 10 Marsden Street, Manchester. [*Namoh, Manchester.* 637.]

1895. Homfray, Samuel George, Sir W. G. Armstrong, Mitchell and Co., 8 Great George Street, Westminster, S.W.

1890. Hooker, Benjamin, Pear Tree Court, Farringdon Road, London, E.C.

1892. Hope, John Basil, Locomotive Department, North Eastern Railway Leeds.

1866. Hopkins, John Satchell, Jesmond Grove, Highfield Road, Edgbaston, Birmingham.

1885. Hopkinson, Charles, Werneth Chambers, 29 Princess Street, Manchester.

1894. Hopkinson, Edward, D.Sc., Messrs. Mather and Platt, Salford Iron Works, Manchester.

1856. Hopkinson, John, Inglewood, St. Margaret's Road, Bowdon, near Altrincham.

1874. Hopkinson, John, Jun., D.Sc., F.R.S., 5 Victoria Street, Westminster, S.W. [3092.]

1877. Hopkinson, Joseph, Messrs. Joseph Hopkinson and Co., Britannia Works, Huddersfield.

1890. Hopper, Allan, Messrs. William Hopper and Co., Moscow, Russia.

1890. Hopper, James Russell, Messrs. William Hopper and Co., Moscow, Russia.

1889. Hopwood, John, Locomotive Superintendent, Argentine Great Western Railway, Mendoza, Argentine Republic.

1891. Hornbrook, Raymond Hillman, care of General Post Office, San Francisco, California.

1895. Horner, John, Clonard Foundry, Belfast.

1880. Hornsby, James, Messrs. Richard Hornsby and Sons, Spittlegate Iron Works, Grantham. [*Hornsbys, Grantham.*]

1889. Horsfield, Cooper, Messrs. Holroyd Horsfield and Wilson, Larchfield Foundry, Hunslet Road, Leeds.

1891. Horsfield, Ralph, Messrs. Ralph Horsfield and Co., Chapel-en-le-Frith, near Stockport.

1873. Horsley, Charles, 22 Wharf Road, City Road, London, N.

1892. Horsnell, Daniel, 79 Farringdon Road, London, E.C.

1868. Horton, Enoch, Alma Works, Darlaston, near Wednesbury.

1871. Horton, George, 4 Cedars Road, Clapham Common, London, S.W.

1886. Hosgood, John Howell, Locomotive and Hydraulic Superintendent, Barry Dock and Railways, Barry, near Cardiff.

1889. Hosken, Richard, Severn Tunnel Works, Sudbrook, near Chepstow.

1873. Hoskin, Richard, 8 Norfolk Street, Sheffield.

1892. Houghton, Francis Gassiot, 17 Victoria Street, Westminster, S.W.

1866. Houghton, John Campbell Arthur, Woodside Iron Works, near Dudley.

1889. Houghton, Thomas Harry, 58 Pitt Street, Sydney, New South Wales: (or care of Messrs. James Simpson and Co., 101 Grosvenor Road, Pimlico, London, S.W.) [*Expansion, Sydney.*]

1887. Houghton-Brown, Ernest, Messrs. Houghton-Brown Brothers, Kingsbury Iron Works, Ballspond, London, N.

1891. How, William Field, Mutual Life Buildings, George Street, Sydney, New South Wales. [*Alaska, Sydney.*]

1864. Howard, Eliot, Messrs. Hayward Tyler and Co., 84 Upper Whitecross Street, London, E.C.

1879. Howard, James Harold, Britannia Iron Works, Bedford; and Kempston Grange, Bedford.

1882. Howard, John William, Gloucester Wagon Works, Gloucester.

1885. Howarth, William, Manager, Oldham Boiler Works, Oldham. [*Boilers, Oldham.*]

1861. Howell, Joseph Bennett, Messrs. Howell and Co., Brook Steel Works, Brookhill, Sheffield [*Howell, Sheffield.*]; and The Tower, Hathersage, near Sheffield.

1877. Howell, Samuel Earnshaw, Messrs. Howell and Co., Brook Steel Works, Brookhill, Sheffield. [*Howell, Sheffield.*]

1892. Howitt, James John, Messrs. Bowman Thompson and Co., Lostock Gralam, Northwich.

1882. Howl, Edmund, Messrs. Lee Howl and Co, Tipton. [*Howl, Tipton.*]

1877. Howlett, Francis, Messrs. Henry Clayton Son and Howlett, Atlas Works, Woodfield Road, Harrow Road, London, W. [*Brickpress, London.*]

1891. Hoy, Henry Albert, Locomotive Works, Lancashire and Yorkshire Railway, Horwich, near Bolton.

1887. Hoyle, James Rossiter, Messrs. Thomas Firth and Sons, Norfolk Works, Sheffield.

1891. Hubback, Charles Arbuthnot, 9 Church Crescent, St. Albans.

1882. Hudson, John George, Messrs. Hick Hargreaves and Co., Soho Iron Works, Crook Street, Bolton; and Glenholme, Bromley Cross, Bolton.

1884. Hudson, Robert, Gildersome Foundry, near Leeds [*Gildersome, Leeds.* 14.]; and Weetwood Mount, Headingley, near Leeds. [454.]

1893. Hudson, William, Ahmedabad, Bombay, India.

1881. Hughes, Edward William Mackenzie, 33 Renfield Street, Glasgow; and Madgefield, Helensburgh.

1867. Hughes, George Douglas, Messrs. G. D. Hughes and Son, Queen's Foundry, London Road, Nottingham.

1889. Hughes, John, Messrs. Hughes and Lancaster, 47 Victoria Street, Westminster, S.W.

1871. Hughes, Joseph, Kingston, Wareham.

1891. Hughes, Robert M., care of Reginald D. Hughes, 27 St. Mary's Terrace, Paddington, London, W.

1892. Hullah, Arthur, Victoria Jubilee Technical Institute, Byculla, Bombay, India: (or care of Walter Hunter, 12 Chetwynd Terrace, Meadow Road, Leeds.)

1883. Hulse, Joseph Whitworth, Messrs. Hulse and Co., Ordsal Works, Regent Bridge, Salford, Manchester. [*Esluh, Manchester.*]

1864. Hulse, William Wilson, Ordsal Works, Regent Bridge, Salford, Manchester. [*Esluh, Manchester.*]

1890. Humphries, Edward Thomas, Wyre, Pershore.

1866. Humphrys, Robert Harry, Messrs. Humphrys Tennant and Co., Deptford Pier, London, S.E.

1894. Humpidge, James Dickerson, Messrs. Humpidge, Holborow and Co., Dudbridge Iron Works, Stroud, Gloucestershire [*Humpidge, Cainscross.*]; and Glengar, Frome Park Road, Stroud, Gloucestershire.

1885. Hunt, Richard, Messrs. Thomas Hunt and Sons, Albion Iron Works, 132 Bridge Road West, Battersea, London, S.W.

1856. Hunt, Thomas, Egerton Mount, Heaton Chapel, R.O., Stockport.

1874. Hunt, William, Alkali Works, Lea Brook, Wednesbury; Hampton House, Wednesbury; and Aire and Calder Chemical Works, Castleford, near Normanton.

1889. Hunter, Charles Lafayette, Engineer, Bute Docks, Cardiff.

1886. Hunter, John, Messrs. Campbells and Hunter, Dolphin Foundry, Saynor Road, Hunslet, Leeds.

1877. Hunter, Walter, Messrs. Hunter and English, High Street, Bow, London, E. [*Venator, London.*]

1888. Huxley, George, 20 Mount Street, Manchester.

1885. Hyland, John Frank, Railway Contractor, São Carlos do Pinhal, Estado de São Paulo, Brazil: (or care of Messrs. Lewis and Hyland, New Rents, Ashford, Kent.)

1877. Imray, John, Messrs. Abel and Imray, 20 Southampton Buildings, London, W.C.

1882. Ingham, William, Assistant Engineer, National Boiler Insurance Co., 22 St. Ann's Square, Manchester.

1888. Ingleby, Joseph, 20 Mount Street, Manchester.

1883. Instone, Thomas, 146 Leadenhall House, Leadenhall Street, London, E.C.

1894. Iorns, Charles Risbec, Messrs. George Richards and Co., Atlantic Works, Broadheath, near Manchester.

1892. Irons, Thomas, Messrs. Hudson Brothers, Clyde Engineering Works, Granville, New South Wales.

1894. Irwin, Thomas F., Messrs. Irwin and Atkinson, 2A Tower Chambers, Old Church Yard, Liverpool. [*Irwall, Liverpool.* 2399.]

1895. Isaac, Robert, Messrs. Owen, Isaac and Owen, Union Iron Works, Portmadoc. [*Isaac, Portmadoc.*]

1887. Ivatt, Henry Alfred, Locomotive Engineer, Great Southern and Western Railway, Inchicore Works, near Dublin.

1887. Ivatts, Lionel Edward, Hapetenea, Behobie, Basses-Pyrénées, France.

1884. Jacks, Thomas William Moseley, Patent Shaft Works, Wednesbury; and Woodgreen, Wednesbury.

1894. Jackson, John Broad, Messrs. Bentley and Jackson, Lodge Bank Works, Bury, Lancashire.

1847. Jackson, Peter Rothwell, Salford Rolling Mills, Manchester; and Blackbrooke, Pontrilas, R.S.O., Herefordshire. [*Jacksons, Manchester.*]

1895. Jackson, Robert Cattley, Newcastle-on-Tyne Electric Supply Co., Pandon Dene, Newcastle-on-Tyne. [*Supply, Newcastle-on-Tyne.* 530.]

1873. Jackson, Samuel, C.I.E., 23 Calverley Park, Tunbridge Wells.

1886. Jackson, Thomas, 41 Wesley Road, Armley, Leeds.

1889. Jackson, William, Thorn Grove, Mannofield, Aberdeen.

1876. Jacobs, Charles Mattathias, 88 Bishopsgate Street Within, London, E.C. [*Vexillum, London.*]

1878. Jakeman, Christopher John Wallace, Manager, Messrs. Merryweather and Sons, Tram Locomotive Works, Greenwich Road, London, S.E.

1893. James, Arthur William, Messrs. K. L. Mukerjee and Co., 19 Sukea's Lane, Calcutta, India.

1889. James, Charles William, Gwynant, Avington Grove, Penge, London, S.E.

1877. James, Christopher, 4 Alexandra Road, Clifton, Bristol.

1895. James, Christopher William, Messrs. Joshua Buckton and Co., Well House Foundry, Meadow Road, Leeds.

1895. James, Enoch, Works Manager, Dowlais Iron Works, Cardiff.

1877. James, John William Henry, 28 Victoria Street, Westminster, S.W.

1889. James, Reginald William, 1 Queen Victoria Street, London, E.C.

1879. Jameson, George, Glencormac, Bray, Ireland.

1881. Jameson, John, Messrs. Jameson and Schaeffer, Akenside Hill, Newcastle-on-Tyne. [*Jameson, Newcastle-on-Tyne.* 226.]

1888. Jaques, Captain William Henry, Messrs. See and Jaques, 1 Broadway, New York, United States. [*Menudeo, New York.*]

1888. Jeejeebhoy, Piroshaw Bomanjee, 17 Church Street, Bombay, India.

1880. Jefferies, John Robert, Messrs. Ransomes Sims and Jefferies, Orwell Works, Ipswich.

1881. Jefferiss, Thomas, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham. [*Tangyes, Birmingham.*]

1877. Jeffreys, Edward Homer, Hawkhills, Chapel Allerton, Leeds.

1893. Jenkin, Charles Frewen, Messrs. Nettlefolds, Castle Works, Tydu, near Newport, Monmouthshire.

1894. Jenkin, Thomas Henry, Messrs. J. Jamieson and Co., Queen's Dock Chambers, Hull. [*Propeller, Hull.* 94.]

1880. Jenkins, Rhys, Patent Office, 25 Southampton Buildings, London, W.C.

1892. Jenkins, William John, Albion Iron Works, Miles Platting, Manchester.

1893. Jennins, Henry Horwood, Messrs. Edwin Oldroyd and Co., Crown Works, Leeds.

1878. Jensen, Peter, 77 Chancery Lane, London, W.C. [*Venture, London.*]

1889. Jessop, George, Messrs. Jessop and Appleby Brothers, Steam-Crane and Engine Works, Leicester. [*Jessop, Leicester.*]

1885. Johnson, John Clarke, Messrs. James Russell and Sons, Crown Tube Works, Wednesbury.

1890. Johnson, John William, care of Baron L. Knoop, Maison du Banque des Marchands, Ilyinka, Moscow, Russia.

1891. Johnson, Lacey Robert, Master Mechanic, Pacific Division, Canadian Pacific Railway, Vancouver, British Columbia.

1888. Johnson, Lawrence Potter, District Locomotive Superintendent, Burma State Railway, Insein, Lower Burma; and 9 Blackheath Rise, Lewisham, London, S.E.

1882. Johnson, Samuel, Manager, Globe Cotton and Woollen Machine Works, Rochdale; and Glebelands, Rochdale.

1887. Johnson, Samuel Henry, Engineering Works, Carpenter's Road, Stratford, London, E.; and The Warren Hill, Loughton, Essex.

1861. Johnson, Samuel Waite, Locomotive Superintendent, Midland Railway, Derby.

1888. Johnson, William, Castleton Foundry and Engineering Works, Armley Road, Leeds.

1891. Johnston, Andrew, Bank Buildings, Hong Kong, China. [*Marine, Hong Kong.*]

1895. Johnstone, Captain James Henry L'Estrange, R.E., Horse Guards, Whitehall, London, S.W.

1872. Joicey, Jacob Gowland, Messrs. J. and G. Joicey and Co., Forth Banks West Factory, Newcastle-on-Tyne. [*Engines, Newcastle-on-Tyne.*]

1882. Jolin, Philip, 35 Narrow Wine Street, Bristol; and 2 Elmdale Road, Redland, Bristol.

1891. Jones, Charles Frederick, 85 Davenport Street, Bolton.

1871. Jones, Charles Henry, Assistant Locomotive Superintendent, Midland Railway, Derby.

1873. Jones, Edward, Broomfield House, Perry Barr, Birmingham.

1884. Jones, Felix, Messrs. Jones and Foster, 39 Bloomsbury Street, Birmingham.

1878. Jones, Frederick Robert, Superintending Engineer, Sirmoor State, Nahan, near Umballa, Punjaub, India: (or care of Messrs. Richard W. Jones and Co., Newport, Monmouthshire.)

1867. Jones, George Edward, District Locomotive Superintendent, North Western Railway, Quetta, Beluchistan, India: (or care of Mrs. Edward Jones, Homelea, All Saints' Villas, Cheltenham.)

1878. Jones, Harry Edward, Engineer, Commercial Gas Works, Stepney, London, E.

1881. Jones, Herbert Edward, District Locomotive Superintendent, Midland Railway, Manchester.

1890. Jones, Morlais Glasfryn, 6 Delahay Street, Westminster, S.W.

1882. Jones, Samuel Gilbert, Hatherley Court, Gloucester.

1887. Jones, Thomas, Central Board School, Deansgate, Manchester.

1872. Jones, William Richard Sumption, Whitehall Court, London, S.W.

1883. Jordan, Edward, Manager, Cardiff Junction Dry Dock and Engineering Works, Cardiff.

1891. Jordan, Henry George, Jun., Municipal Technical School, Princess Street, Manchester.

1880. Joy, David, 17 Victoria Street, Westminster, S.W.; and Manor Road House, Beckenham.

1891. Judd, Joseph Henry, Head Master, Municipal Technical School, York Place, Brighton.

1878. Jüngermann, Carl, Maschinenbau Actien Gesellschaft Vulcan, Bredow bei Stettin, Germany.

1884. Justice, Howard Rudulph, 55 and 56 Chancery Lane, London, W.C. [*Syng, London.* 65003.]

1889. Kanthack, Ralph, 21 Golden Square, Regent Street, London, W. [*Kanthack, London.*]

1888. Kapteyn, Albert, Westinghouse Brake Co., Canal Road, York Road, King's Cross, London, N.

1869. Keen, Arthur, London Works, near Birmingham. [*Globe, Birmingham.*]

1883. Keen, Francis Watkins, Patent Nut and Bolt Works, Westbromwich.

1873. Kelson, Frederick Colthurst, Angra Bank, Waterloo Park, Waterloo, near Liverpool.

1881. Kendal, Ramsey, Locomotive Department, North Eastern Railway, Darlington.

1879. Kennedy, Professor Alexander Blackie William, LL.D., F.R.S., 14 Old Queen Street, Westminster, S.W. [*Kinematic, London.*]

1863. Kennedy, John Pitt, Bombay Baroda and Central Indian Railway, 45 Finsbury Circus, London, E.C.; and 29 Lupus Street, St. George's Square, London, S.W.

1892. Kennedy, Thomas, The Glenfield Engineering Works, Kilmarnock.

1875. Kenrick, George Hamilton, Messrs. A. Kenrick and Sons, Spon Lane, Westbromwich; and Whetstone, Somerset Road, Edgbaston, Birmingham.

1892. Kensington, Frederick, 2 Copthall Buildings, London, E.C.

1866. Kershaw, John, Marazion, St. Leonard's-on-Sea.

1884. Kershaw, Thomas Edward, Chilvers Coton Foundry, Nuneaton.

1890. Key, George Andrew, General Manager, Wallsend Pontoon Works, Bute Docks, Cardiff.

1885. Keyworth, Thomas Egerton, Ferro Carril Buenos Aires y Rosario, Campana, Buenos Aires, Argentine Republic: (or care of J. R. H. Keyworth, 28 Grosvenor Road, Birkenhead.)

1885. Kidd, Hector, Colonial Sugar Refining Co., Sydney, New South Wales.

1894. Kiernan, George, Manager, Messrs. Gresham and Craven, Craven Iron Works, Salford, Manchester.

1888. Kikuchi, Kyozo, Superintendent Engineer, Hirano Spinning Mill, Osaka, Japan.

1895. King, Charles Penrose, Resident Engineer, Epsom Water Works, Epsom.

1895. King, Thomas Scott, Works Manager, Messrs. Clench and Co., Lincoln Works, Chesterfield.

1872. King, William, Engineer, Liverpool United Gas Works, Duke Street, Liverpool.

1893. Kinghorn, John Warden, care of Messrs. Jardine Matheson and Co., Hong Kong, China.

1889. Kirby, Frank Eugene, Constructing Engineer, Detroit Dry Dock Co., Detroit, Michigan, United States.

1877. Kirk, Henry, Messrs. Kirk Brothers and Co., New Yard Iron Works, Workington. [*Kirks, Workington.*]

1884. Kirkaldy, John, 40 West India Dock Road, London, E. [*Compactum, London.*]

1875. Kirkwood, James, Chief Inspector of Machinery for Pei Yang Squadron; care of Commissioner of Customs, Kowloon, Hong Kong, China: (or Melita Cottage, Denny.)

1864. Kirtley, William, Locomotive Superintendent, London Chatham and Dover Railway, Longhedge Works, Wandsworth Road, London, S.W. [3005.]

1859. Kitson, Sir James, Bart., M.P., Monk Bridge Iron Works, Leeds.

1868. Kitson, John Hawthorn, Airedale Foundry, Leeds. [*Airedale, Leeds.*]

1874. Klein, Thorvald, 50 Southbrook Road, Lee, London, S.E.

1889. Knap, Conrad, 11 Queen Victoria Street, London, E.C.

1891. Knight, Bertrand Thornton, Post Office, Perth, Western Australia: (or care of Major Knight, Swansea.)

1886. Knight, Charles Albert, Babcock and Wilcox Co., 21 Bothwell Street, Glasgow.

1890. Knight, James Percy, Kaiser Steam Tug Co., 27 Great Tower Street, London, E.C. [*Longboat, London.* 11,203.]

1881. Laing, Arthur, Deptford Shipbuilding Yard, Sunderland.

1872. Laird, William, Messrs. Laird Brothers, Birkenhead Iron Works, Birkenhead. [*Laird, Birkenhead.* 4003.]

1883. Lake, William Robert, 45 Southampton Buildings, London, W.C. [*Scopo, London.*]

1881. Langdon, William, Locomotive Superintendent and Chief Mechanical Engineer, Rio Tinto Railway and Mines, Huelva, Spain: (or care of T. C. Langdon, Tamar Terrace, Launceston.)

1881. Lange, Frederick Montague Townshend, 53 bis Boulevard de la Liberté, Lille (Nord), France.

1893. Langford, William, Messrs. W. M. Ward and Co., Limerick Foundry, Great Bridge, Tipton.

1879. Lapage, Richard Herbert, Oakfield, Langley Avenue, Surbiton, London, S.W.

1890. Last, Lieutenant Arthur John, R.A., Inspector of Ordnance Machinery, Mauritius.

1888. Latham, Baldwin, 13 Victoria Street, Westminster, S.W.; and Duppas House, Old Town, Croydon.

1890. Laurie, Leonard George, Mill Parade, Newport, Monmouthshire.

1867. Lawrence, Henry, The Grange Iron Works, Durham.

1893. Lawrie, James, Assistant Government Marine Surveyor, Singapore, Straits Settlements.

1874. Laws, William George, Borough Engineer and Town Surveyor, Town Hall, Newcastle-on-Tyne; and 5 Winchester Terrace, Newcastle-on-Tyne. [*Engineer, Newcastle-on-Tyne.*]

1882. Lawson, Frederick William, Messrs. Samuel Lawson and Sons, Hope Foundry, Leeds.

1870. Layborn, Daniel, Messrs. Daniel Layborn and Co., Dutton Street, Liverpool.

1883. Laycock, William S., Victoria Street Works, Sheffield; and Ranmoor, Sheffield. [*Invention, Sheffield.* 907.]

1860. Lea, Henry, Messrs. Henry Lea and Thornbery, 38 Bennett's Hill, Birmingham. [*Engineer, Birmingham.* 113.]

1892. Lea, Richard Henry, Stoke Green, Coventry.

1895. Lea, William Arthur, Galt and Preston Street Railway, Preston, Ontario, Canada.

1889. Leaf, Henry Meredith, Burlington Lodge, Streatham Common, London, S.W.

1883. Leavitt, Erasmus Darwin, Jun., 604 Main Street, Cambridgeport, Massachusetts, United States.

1890. Ledingham, John Machray, Royal Laboratory, Royal Arsenal, Woolwich.

1887. Lee, Cuthbert Ridley, Messrs. J. Coates and Co., Suffolk House, Laurence Pountney Hill, London, E.C.

1862. Lee, J. C. Frank, 6 Great Winchester Street, London, E.C.

1892. Lee, Richard John, Messrs. Harrison Lee and Sons, City Foundry, Limerick.

1890. Lee, Samuel Edward, Messrs. Harrison Lee and Sons, City Foundry, Limerick.

1863. Lees, Samuel, Messrs. H. Lees and Sons, Park Bridge Iron Works, Ashton-under-Lyne.

1889. Legros, Lucien Alphonse, 57 Brook Green, Hammersmith, London, W.

1883. Lennox, John, 28 Victoria Street, Westminster, S.W.

1883. Leslie, Joseph, 3 Canal Street, North Road, Entally, Calcutta, India.

1888. Letchford, Joseph, Sefton Lodge, South Park Road, Wimbledon.

1878. Lewis, Gilbert, 538 Eccles New Road, Eccles, Manchester.

1884. Lewis, Henry Watkin, Llwyn-yr-eos, Abercanaid, near Merthyr Tydfil.

1895. Lewis, Herbert William, Acting Senior Inspector of Boilers, Custom House, Bombay, India.

1872. Lewis, Richard Amelius, Messrs. John Spencer and Sons, Tyne Hæmatite Iron Works, Scotswood-on-Tyne.

1884. Lewis, Sir William Thomas, Bute Mineral Estate Office, Aberdare; and Mardy, Aberdare.

1894. Liebert, Henry Anton, Messrs. John Holroyd and Co., Tomlinson Street, Hulme, Manchester.

1880. Lightfoot, Thomas Bell, Cornwall Buildings, 35 Queen Victoria Street, London, E.C. [*Separator, London.*]; and 7 Eastcombe Villas, Charlton Road, Blackheath, London, S.E.

1891. Lindsay, William Robertson, 1 Lorne Terrace, Forfar Road, Dundee.

1890. Lineham, Wilfrid James, Professor of Engineering and Mechanical Science, The Goldsmiths' Institute, New Cross, London, S.E.; and Jesmond, Leyland Road, Lee, London, S.E.

1856. Linn, Alexander Grainger, 121 Upper Parliament Street, Liverpool.

1876. Lishman, Thomas, Mining Engineer, Hetton Colliery, near Fence Houses.

1881. List, John, Superintendent Engineer, Messrs. Donald Currie and Co., Orchard Works, Blackwall, London, E.; and 3 St. John's Park, Blackheath, London, S.E.

1885. Lister, Frank, Messrs. Lister and Co., Beechcliffe, Keighley; and Oaklands, Keighley.

1890. Lister, Robert Ramsbottom, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1866. Little, George, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham; and Colliston, Park Road, Southport.

1890. Livens, Frederick Howard, Messrs. Ruston Proctor and Co., Sheaf Iron Works, Lincoln.

1895. Livingston, James, 186 Gresham House, Old Broad Street, London, E.C.

1886. Livsey, John Edward, Demonstrator in Mechanics and Mathematics, Royal College of Science, Exhibition Road, South Kensington, London, S.W.

1867. Lloyd, Charles, 73 Boundary Road, St. John's Wood, London, N.W.

1854. Lloyd, George Braithwaite (*Life Member*), Edgbaston Grove, Birmingham.

1882. Lloyd, Robert Samuel, Messrs. Hayward Tyler and Co., 84 Upper Whitecross Street, London, E.C.

1894. Lloyd, Sampson Zachary, Managing Director, Engineering Department, Messrs. Nettlefolds, Birmingham [*Nettlefolds, Birmingham.*]; and Areley Hall, Stourport.

1890. Locke, Arthur Guy Neville, Alderney, Channel Isles.

1879. Lockhart, William Stronach, 5 Haddo Villas, Blackheath, London, S.E.

1884. Logan, Andrew Linton, Railway Signal Works, Worcester.

1890. Logan, John Walker, Messrs. Davey Paxman and Co., Standard Iron Works, Colchester; and P.O. Box 2037, Johannesburg, Transvaal, South Africa.

1883. Logan, Robert Patrick Tredennick, Engineer's Office, Great Northern Railway of Ireland, Dundalk.

1884. Longbottom, Luke, Locomotive Carriage and Wagon Superintendent, North Staffordshire Railway, Stoke-on-Trent.

1894. Longridge, Captain Cecil Clement, Managing Director, Axle-box and Foundry Co., Central Works, Saltley, Birmingham. [*Beuthers, Birmingham.*]

1880. Longridge, Michael, Chief Engineer, Engine and Boiler Insurance Co., 12 King Street, Manchester.

1856. Longridge, Robert Bewick, Managing Director, Engine and Boiler Insurance Co., 12 King Street, Manchester; and Yew Tree House, Tabley, near Knutsford.

1875. Longridge, Robert Charles, Kilrie, Knutsford.

1880. Longworth, Daniel, 17 Walpole Street, Sloane Square, London, S.W.

1887. Lorrain, James Grieve, Norfolk House, Norfolk Street, London, W.C. [*Lorrain, London.*]

1888. Low, David Allan, Head Master, The People's Palace Day Technical School, Mile End Road, London, E.

1885. Low, Robert, Powis Lodge, Vicarage Park, Plumstead.

1884. Lowcock, Arthur, Coleham Foundry, Shrewsbury.

1884. Lowdon, John, General Manager, Barry Graving Dock and Engineering Co., Exchange Buildings, Cardiff. [*Bardock, Cardiff.*]

1891. Lowdon, Thomas, Kingsland Crescent, Barry Docks, B.O., near Cardiff.

1873. Lowe, John Edgar, Messrs. Bolling and Lowe, 2 Laurence Pountney Hill, London, E.C. [*Bird, London.* 1530.]

1873. Lucas, Arthur, 27 Bruton Street, New Bond Street, London, W.

1889. Lucy, Arthur John, Meadowcroft, Penn Road, Croydon.

1886. Lucy, William Theodore, care of Frank Hudson, Central Uruguay Railway, Monte Video, Uruguay: (or Thornleigh, Woodstock Road, Oxford.)

1895. Lumsden, Thomas Templeton Mackie, Managing Director, Messrs. James Milne and Son, Milton House Works, Edinburgh.

1877. Lupton, Arnold, Professor of Mining Engineering, Yorkshire College, Leeds; and 6 De Grey Road, Leeds. [*Arnold Lupton, Leeds.* 330.]

1887. Lupton, Kenneth, Messrs. K. and H. Lupton, Well Street, Coventry. [*Luptons, Coventry.* 77.]

1878. Lynde, James Henry, Buckland, Ashton-on-Mersey, near Manchester.

1889. Macallan, George, Works Manager, Great Eastern Railway, Stratford Works, London, E.

1890. Macan, Richard Thompson, Dawlish House, Willesden, London, N.W.

1892. Macbean, John James, Messrs. Howarth Erskine and Co., Singapore, Straits Settlements.

1888. Macbeth, John Bruce King, 44 Tamarind Lane, Bombay, India: (or care of Norman Macbeth, Heaton, Bolton.)

1883. Macbeth, Norman, Messrs. John and Edward Wood, Victoria Foundry, Bolton.

1884. MacCarthy, Samuel, Messrs. Lloyd and Lloyd, 90 Cannon Street, London, E.C.; and 18 Adelaide Road, Brockley, London, S.E.

1877. MacColl, Hector, Strandtown, Belfast.

1889. Macdonald, James Alexander, Broad Oaks Iron Works, Chesterfield.

1895. MacGarvey, Howard, Lombard Street Works, Dublin.

1892. Machado, Dr. Antonio Augusto, Manager, Companhia Metropolitana, Engineering and Boiler Works, Bahia, Brazil: (or care of Messrs. Heuser Humble and Co., 1 Fowkes Buildings, Great Tower Street, London, E.C.)

1892. Mackay, Charles O'Keefe, Locomotive Department, Lancashire and Yorkshire Railway, Horwich, near Bolton.

1890. Mackay, Joseph, Bangkok Dock Co., Bangkok, Siam: (or care of Messrs. John Birch and Co., 10 Queen Street Place, London, E.C.) [*Mackay, Bangkok.*]

1885. Mackenzie, John William, Messrs. Wheatley and Mackenzie, 40 Chancery Lane, London, W.C.; and Northfield, Oxford Road, Upper Teddington, S.O., Middlesex.

1894. Mackie, John, 165 King's Road, Reading.

1875. Maclagan, Robert, Blantyre, British Central Africa: (or care of Dr. Maclagan, 9 Cadogan Place, Belgrave Square, London, S.W.)

1889. MacLay, Alexander, Professor of Mechanical Engineering, Glasgow and West of Scotland Technical College, 38 Bath Street, Glasgow.

1886. MacLean, Alexander Scott, Messrs. Alexander Scott and Sons, Sugar Refinery, Berry-yards, Greenock; and 31 Bank Street, Greenock.

1877. MacLellan, John A., Messrs. Alley and MacLellan, Sentinel Works, Polmadie Road, Glasgow. [*Alley, Glasgow.* 673.]

1864. Macnab, Archibald Francis, Tokyo, Japan.

1884. Macpherson, Alexander Sinclair, Messrs. Fairbairn Naylor Macpherson and Co., Wellington Foundry, Leeds.

1892. Mactear, James, F.R.S.E., 28 Victoria Street, Westminster, S.W. [*Celestine, London.* 3066.]

1879. Maginnis, James Porter, 9 Carteret Street, Queen Anne's Gate, Westminster, S.W. [*Offsett, London.*]

1891. Mahon, Captain Reginald Henry, R.A., Superintendent, H. M. Shell Factory, Cossipore, Calcutta, India.

1873. Mair-Rumley, John George (*Life Member*), Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W. [*Aquosity, London.*]

1884. Mais, Henry Coathupe, 2 Prell's Buildings, Collins and Queen Streets, Melbourne, Victoria.

1883. Malan, Ernest de Mérindol, Westinghouse Brake Co., York Road, King's Cross, London, N.

1879. Malcolm, Bowman, Locomotive Superintendent, Belfast and Northern Counties Railway, Belfast.

1891. Manisty, Edward, Dundalk Iron Works, Dundalk, Ireland; and 24A Bryanston Square, London, W.

1894. Mann, James Hutchinson, Messrs. Mann and Charlesworth, Canning Works, Dewsbury Road, Leeds. [*Canning, Leeds.* 1335.]

1888. Mano, Bunji, Professor of Mechanical Engineering, Imperial University, Tokyo, Japan.

1875. Mansergh, James, 5 Victoria Street, Westminster, S.W.

1894. Mansfield, Edwin, Messrs. Edwin Mansfield and Sons, 140 Great Clowes Street, Broughton, Manchester. [*Gaslight, Manchester.*]

1891. Manson, James, Locomotive Superintendent, Glasgow and South Western Railway, Kilmarnock.

1862. Mappin, Sir Frederick Thorpe, Bart., M.P., Messrs. Thomas Turton and Sons, Sheaf Works, Sheffield; and Thornbury, Sheffield.

1878. Marié, Georges, Ingénieur Chef de Division, Chemins de fer de Paris à Lyon et à la Méditerranée, 7 Rue du Clos d' Orléans, Fontenay-sous-Bois, Seine, France.

1891. Marks, Edward Charles Robert, 13 Temple Street, Birmingham.

1888. Marks, George Croydon, 13 Temple Street, Birmingham. [*Pumps, Birmingham.*]

1884. Marquand, Augustus John, 2 Dock Chambers, Bute Docks, Cardiff. [*Martial, Cardiff.*]

1887. Marriott, William, Engineer and Locomotive Superintendent, Midland and Great Northern Joint Railways, Melton Constable, Norfolk.

1887. Marsden, Benjamin, Messrs. S. Marsden and Son, Screw-Bolt and Nut Works, London Road, Manchester.

1871. Marsh, Henry William, Winterbourne, near Bristol.

1875. Marshall, Rev. Alfred (*Life Member*), The Vicarage, Feckenham, Redditch.

1865. Marshall, Francis Carr, Messrs. R. and W. Hawthorn Leslie and Co., St. Peter's Works, Newcastle-on-Tyne.

1890. Marshall, Frank Herbert, Ormesby Iron Works, Middlesbrough.

1885. Marshall, Henry Dickenson, Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough. [*Marshalls, Gainsborough.* 6648.]

1871. Marshall, James, Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough. [*Marshalls, Gainsborough.* 6648.]

1885. Marshall, Jenner Guest, Messrs. Chance Brothers and Co., Glass Works, near Birmingham; and Westcott Barton Manor, Oxfordshire.

1877. Marshall, William Bayley, Richmond Hill, Edgbaston, Birmingham. [*Augustus, Birmingham.*]

1847. Marshall, William Prime, Richmond Hill, Edgbaston, Birmingham. [*Augustus, Birmingham.*]

1859. Marten, Edward Bindon, Pedmore, Stourbridge. [*Marten. Stourbridge.* 8504.]

1881. Martin, Edward Pritchard, Dowlais Iron Works, Dowlais.

1888. Martin, Henry James, 29 Bryn-y-mor Road, Swansea.

1889. Martin, The Hon. James, Messrs. James Martin and Co., Phœnix Foundry, Gawler, South Australia: (or care of J. C. Lanyon, 27 Gresham House, Old Broad Street, London, E.C.)

1892. Martin, Thomas George, Messrs. James McGowan and Co., Wapping Wall, London, E.

1886. Martin, William Hamilton, Engineering Manager, The Scheldt Royal Shipbuilding and Engineering Works, Flushing, Holland.

1882. Martindale, Warine Ben Hay, 38 Parliament Street, Westminster, S.W.; and Overfield, Bickley, R.S.O., Kent.

1882. Masefield, Robert, 14 Markham Square, Chelsea, London, S.W.

1884. Massey, George, Post Office Chambers, Pitt Street, Sydney, New South Wales.

1890. Massey, Stephen, Messrs. B. and S. Massey, Openshaw, Manchester.

1893. Massey, William Henry, 25 Queen Anne's Gate, Westminster, S.W.; and Twyford, R.S.O., Berkshire.

1892. Masterton, John Fraser, Locomotive Department, South Eastern Railway, Ashford, Kent.

1894. Mather, George Radford, Messrs. G. R. Mather and Son, Albion Foundry, Wellingborough. [*Mather, Wellingborough.*]

1867. Mather, William, Messrs. Mather and Platt, Salford Iron Works, Manchester. [*Mather, Manchester.*]

1883. Mather, William Penn, Queen Dyeing Co., Providence, Rhode Island, United States.

1882. Matheson, Henry Cripps, Enfield, Sunny Gardens, Hendon, London, N.W.

1891. Mathewson, Jeremiah Eugene, Tilghman's Sand-Blast Co., Bellefield Works, Bellefield Lane, Sheffield.

1886. Matthews, Robert, Parrs House, Heaton Mersey, near Manchester.

1895. Matthews, Thomas, Imperial Iron Works, West Gorton, Manchester.

1853. Maudslay, Henry (*Life Member*), Westminster Palace Hotel, 4 Victoria Street, Westminster, S.W.: (or care of John Barnard, 47 Lincoln's Inn Fields, London, W.C.)

1893. Maunsell, Richard Edward Lloyd, Locomotive Department, East Indian Railway, Jamalpur, Bengal, India: (or care of John Maunsell, Edenmore, Raheny, Co. Dublin.)

1873. Maw, William Henry, 35 Bedford Street, Strand, London, W.C. [3663.]

1884. Maxim, Hiram Stevens, Maxim Nordenfelt Guns and Ammunition Co., 32 Victoria Street, Westminster, S.W.; and 18 Queen's Gate Place, South Kensington, London, S.W.

1859. Maylor, William, Chesterleigh, Albemarle Road, Beckenham.

1874. McClean, Frank, Norfolk House, Norfolk Street, Strand, London, W.C.

1891. McCredie, Arthur Latimer, 250 Pitt Street, Sydney, New South Wales. [*Ebony, Sydney.* 63.]

1892. McDonald, John, Locomotive Works, Imperial Government Railways, Tokyo, Japan.

1878. McDonald, John Alexander, Assistant Engineer for Roads and Bridges, Public Works Office, Sydney, New South Wales: (or care of James E. McDonald, 4 Chapel Street, Cripplegate, London, E.C.)

1865. McDonnell, Alexander, 28 Victoria Street, Westminster, S.W.; and The Cedars, Norwood Green, Southall.

1891. McFarlane, George, Sun Insurance Buildings, 121 West George Street, Glasgow. [*Dunsloy, Glasgow.* 3777.]

1895. McFarlane, James, 10A Spring Gardens, Abbeyhill, Edinburgh.

1895. McGee, Walter, Albion Works, Stoney Brae, Paisley. [137.]

1892. McGregor, Peter (*Life Member*), Imperial Maritime Customs, Kowloon, Hong Kong, China.

1889. McIntyre, John Henry A., Lecturer on Mechanical Engineering, Allan Glen's School, Glasgow.

1880. McLachlan, John, Messrs. Bow McLachlan and Co., Thistle Engine Works, Paisley. [*Bow, Paisley.*]

1888. McLaren, Henry, Messrs. J. and H. McLaren, Midland Engine Works, Leeds.

1882. McLaren, Raynes Lauder, 10 Lammas Park Gardens, Ealing, London, W.

1888. McLarty, Farquhar Matheson, Penang Foundry, Penang: (or care of William Bow, Thistle Engine Works, Paisley.) [*McLarty, Penang.*]

1885. McNeil, John, Messrs. Aitken McNeil and Co., Helen Street, Govan, Glasgow. [*Colonial, Glasgow.*]

1894. McQueen, John, Messrs. John Hetherington and Sons, Vulcan Works, Pollard Street, Manchester.

1891. Meade, Thomas de Courcy, Town Hall, Manchester; and Kenmore, Didsbury, Manchester.

1882. Meats, John Tempest, Mason Machine Works, Taunton, Massachusetts, United States.

1881. Meik, Charles Scott, care of P. Walter Meik, 16 Victoria Street, Westminster, S.W.

1858. Meik, Thomas, 13 Newbattle Terrace, Edinburgh.

1887. Melhuish, Frederick, Assistant Engineer, Southwark and Vauxhall Water Works, Southwark Bridge Road, London, S.E.

1891. Melville, William Charles, Superintendent Engineer, Liverpool Steam Tug Co., 44 Chapel Street, Liverpool.

1888. Melville, William Wilkie, Messrs. Caddy and Co., Daybrook, Nottingham.

1878. Menier, Henri, 56 Rue de Châteaudun, Paris.

1876. Menzies, William, Messrs. Menzies and Co., 50 Side, Newcastle-on-Tyne. [*William Menzies, Newcastle-on-Tyne. G.P.O.* 200. *Nor. Dis.* 1144.]

1894. Merrick, Robert, Warren's Place Iron Works, Cork.

1875. Merryweather, James Compton, Messrs. Merryweather and Sons, Fire-Engine Works, Greenwich Road, London, S.E.; and 63 Long Acre, London, W.C. [*Merryweather, London.*]

1891. Metcalfe, Frederick Spencer, Pumping Station, Sewage Works, Burton-on-Trent.

1881. Meysey-Thompson, Arthur Herbert, Messrs. Hathorn Davey and Co., Sun Foundry, Dewsbury Road, Leeds.

1877. Michele, Vitale Domenico de, 14 Delahay Street, Westminster, S.W.; and Higham Hall, Rochester.

1884. Middleton, Reginald Empson, 17 Victoria Street, Westminster, S.W.

1891. Middleton, Robert, Sheepscar Foundry, Leeds.

1891. Middleton, Robert Thomas, Superintendent of Bridge Works, Bombay Baroda and Central India Railway, Bombay, India.

1862. Miers, Francis C., Messrs. Fry Miers and Co., Suffolk House, 5 Laurence Pountney Hill, London, E.C.; and Eden Cottage, West Wickham Road, Beckenham. [*Foundation, London.* 1929.]

1874. Milburn, John, Hawkshead Foundry, Quay Side, Workington.

1887. Miles, Frederick Blumenthal, Messrs. Bement Miles and Co., Callowhill and Twenty-first Streets, Philadelphia, United States.

1893. Millar, Jackson, Messrs. Riley Hargreaves and Co., 11 Merchant Road, Singapore, Straits Settlements: (or care of J. R. Allan, 93 Hope Street, Glasgow.)

1889. Miller, Adam, 50 Lime Street, London, E.C.

1885. Miller, Harry William, Princess Estate and Gold Mining Co., P.O. Box 1366, Johannesburg, Transvaal, South Africa.

1886. Miller, John Smith, Messrs. Smith Brothers and Co., Hyson Green Works, Nottingham.

1887. Miller, Thomas Lodwick, 7 Tower Buildings N., Water Street, Liverpool.

1893. Milligan, William Scott, Messrs. Pollit and Wigzell, Bank Foundry, Sowerby Bridge.

1893. Millington, Frederick Handel, Manager, Patent Pulp Manufacturing Co., Thetford; and Mill House, Thetford.

1885. Millis, Charles Thomas, Principal, Educational Department, Borough Road Polytechnic, London, S.E.

1887. Milne, William, Castle Buildings, West Street, Durban, Natal [*Metallic, Durban*]; and The Oaks, 52 Queen Street, Durban, Natal.

1856. Mitchell, Charles, Sir W. G. Armstrong Mitchell and Co., Low Walker, Newcastle-on-Tyne; and Jesmond Towers, Newcastle-on-Tyne.

1892. Mitcheson, George Arthur, Longton, Staffordshire. [*Mitcheson, Longton.* 445.]

1870. Moberly, Charles Henry, 33 Bennett Park, Blackheath, London, S.E.

1885. Moir, James, Superintendent Engineer, Bombay Steam Navigation Co., Frere Road, Bombay.

1879. Molesworth, Sir Guilford Lindsay, K.C.I.E., The Manor House, Bexley, S.O., Kent.

1882. Molesworth, James Murray, Aberdeen House, Upper Holly Walk, Leamington.

1881. Molinos, Léon, 48 Rue de Provence, Paris.

1884. Monroe, Robert, Manager, Penarth Slipway and Engineering Works, Penarth Dock, Penarth.

1884. Moore, Benjamin Theophilus, Longwood, Bexley, S.O., Kent.

1876. Moore, Joseph, 1099 Adeline Street, Oakland, San Francisco, California: (or care of Ralph Moore, Government Inspector of Mines, 13 Clairmont Gardens, Glasgow.)

1895. Moore, William James Perry, Worthington Pumping Engine Co., 153 Queen Victoria Street, London, E.C.

1880. Moreland, Richard, Messrs. Richard Moreland and Son, 3 Old Street, St. Luke's, London, E.C. [*Expansion, London.*]

1889. Morgan, David John, 16 Barry Dock Road, Barry, near Cardiff.

1885. Morgan, Thomas Rees, Morgan Engineering Works, Alliance, Ohio, United States.

1887. Morison, Donald Barns, Messrs. T. Richardson and Sons, Hartlepool Engine Works, Hartlepool.

1895. Morrin, Richard, Superintendent Engineer, Messrs. Lamport and Holt, 21 Water Street, Liverpool.

1888. Morris, Charles, Messrs. Jessop and Co., Phœnix Iron Works, Calcutta, India.

1874. Morris, Edmund Legh, New River Water Works, Finsbury Park, London, N.

1890. Morris, Francis Sanders, 4 Trafalgar Square, London, W.C.

1890. Morris, John Alfred (*Life Member*), Empire Works, 78 Great Bridgewater Street, Manchester.

1892. Morton, David Home, 95 Bath Street, Glasgow.

1858. Mountain, Charles George, 93 Hope Street, Glasgow.

1886. Mountain, William Charles, Messrs. Ernest Scott and Mountain, Close Works, Newcastle-on-Tyne [*Esco, Newcastle-on-Tyne.* 432.]; and 9 St. George's Terrace, Jesmond, Newcastle-on-Tyne.

1884. Mower, George A., Crosby Steam Gage and Valve Co., 75 Queen Victoria Street, London, E.C. [*Crosby, London.*]

1885. Mudd, Thomas, Manager, Central Marine Engine Works, West Hartlepool.

1873. Muir, Alfred, Messrs. William Muir and Co., Britannia Works, Sherbourne Street, Strangeways, Manchester.

1873. Muir, Edwin, 37 Brown Street, Manchester.

1876. Muirhead, Richard, Kentish Engineering Works, Maidstone. [*Muirhead, Maidstone.*]

1890. Müller, Henry Adolphus, Locomotive Superintendent, Municipal Railway, 3 North Road, Entally, Calcutta, India.

1890. Mumford, Charles Edward, St. Andrew's Works, Bury St. Edmunds.

1890. Munro, John, Professor of Mechanical Engineering, Merchant Venturers' Technical College, Unity Street, Bristol.

1890. Munro, Robert Douglas, Chief Engineer, Scottish Boiler Insurance and Engine Inspection Co., 13 Dundas Street, Glasgow.

1889. Münster, Bernard Adolph, Engineer, Yokohama, Japan.

1891. Murdoch, Robert Macmillan, Phœnix Metal Die and Engineering Co., 40 Coin Street, Stamford Street, London, S.E.

1890. Murray, Alexander John, Chief Mechanical Engineer, Government Gun-Powder Factory, Kirkee, Bombay, India.

1890. Murray, Kenneth Sutherland, Brin's Oxygen Works, 69 Horseferry Road, Westminster, S.W.

1894. Murray, Thomas Roberts, Messrs. L. Sterne and Co., Crown Iron Works, Glasgow.

1881. Musgrave, James, Messrs. John Musgrave and Sons, Globe Iron Works, Bolton. [*Musgrave, Bolton.*]

1882. Musgrave, Walter Martin, Messrs. John Musgrave and Sons, Globe Iron Works, Bolton. [*Musgrave, Bolton.*]

1888. Myers-Beswick, William Beswick (*Life Member*), 14 Victoria Street, Westminster, S.W.

1870. Napier, James Murdoch, Messrs. David Napier and Son, Vine Street, York Road, Lambeth, London, S.E.

1889. Nash, Thomas, Sheffield Testing Works, Blonk Street, Sheffield; and Guzerat House, Nether Edge, Sheffield.

1888. Nathan, Adolphus, Messrs. Larini Nathan and Co., Milan; and 15 Via Bigli, Milan, Italy.

1861. Naylor, John William, Messrs. Fairbairn Naylor Macpherson and Co., Wellington Foundry, Leeds.

1883. Neate, Percy John, 16 The Banks, High Street, Rochester.

1889. Needham, Joseph Edward, Patent Office, 25 Southampton Buildings, London, W.C.

1892. Nelson, Arthur David, Hay and Lackey Streets, Sydney, New South Wales. [*Nelson, Sydney.* 160.]

1884. Nelson, John, Contractors' Office, Dringhouses, York.

1887. Nelson, Sidney Herbert, Messrs. Samuel Worssam and Co., Oakley Works, King's Road, Chelsea, London, S.W.

1881. Nesfield, Arthur, 14 Water Street, Liverpool.

1890. Newton, Percy, Vassall Lodge, Addison Road, Kensington, London, W.

1884. Nicholls, James Mayne, Locomotive Superintendent, Nitrate Railways, Iquique, Chili.

1884. Nicholson, Henry, care of G. H. Hill, Albert Chambers, Albert Square, Manchester.

1894. Nicholson, John Rumney, care of Messrs. Blackburn and Main, Solicitors, Carlisle.

1891. Nicholson, Thomas, Crownpoint Boiler Works, St. Marnock Street, Crownpoint Road, Glasgow.

1886. Noakes, Thomas Joseph, Messrs. Thomas Noakes and Sons, 35 and 37 Brick Lane, Whitechapel, London, E.

1884. Noakes, Walter Maplesden, 73 Clarence Street, Wynyard Square, Sydney, New South Wales.

1892. Norris, William, Messrs. Robey and Co., Globe Iron Works, Lincoln.

1868. Norris, William Gregory, Coalbrookdale Iron Works, Coalbrookdale, Shropshire.

1883. North, Gamble, Pisagua, Chile: Queenswood, Eltham: (or care of B. Depledge, Woolpack Buildings, 3 Gracechurch Street, London, E.C.)

1882. North, John Thomas, Messrs. North Humphrey and Dickenson, Engineering Works, Iquique, Chile; Woolpack Buildings, 3 Gracechurch Street, London, E.C.; and Avery House, Avery Hill, Eltham.

1878. Northcott, William Henry, General Engine and Boiler Co., Hatcham Iron Works, Pomeroy Street, New Cross Road, London, S.E.; and 7 St. Mary's Road, Peckham, London, S.E. [*Oxygen, London.* 8007.]

1888. Norton, William Eardley, 8 Great George Street, Westminster, S.W.

1885. Oakes, Sir Reginald Louis, Bart., Société Anonyme La Métallurgique, 1 Place de Louvain, Bruxelles, Belgium.

1887. O'Brien, Benjamin Thompson, 60 Upper Parliament Street, Liverpool.

1887. O'Brien, John Owden, Messrs. W. P. Thompson and Co., Ducie Buildings, 6 Bank Street, Manchester.

1890. Ockendon, William, Messrs. John Brown and Co., Atlas Steel and Iron Works, Sheffield.

1868. O'Connor, Charles, 144 Osborne Villas, Duke Street, Southport.

1888. O'Donnell, John Patrick, 70 and 71 Palace Chambers, 9 Bridge Street, Westminster, S.W.; and Fingal, Hemmelton Road, Bromley, Kent. [*ODonnell, London.* 3059.]

1889. Ogden, Fred, Patent Office, 25 Southampton Buildings, London, W.C.

1886. Ogle, Percy John, 4 Bishopsgate Street Within, London, E.C. [*Oglio, London.* 2463.]

1894. Oka, Saneyasu, 141, 1 Chome, Funakori Cho, Osaka, Japan.

1893. Oke, Francis Robert, 5 Coppenhall Terrace, Crewe. [*Oke, Crewe.*]

1875. Okes, John Charles Raymond, 63 Queen Victoria Street, London, E.C. [*Oaktree, London.*]

1882. Orange, James, Messrs. Danby Leigh and Orange, Hong Kong, China: (or care of Mrs. Mary Orange, 2 West End Terrace, Jersey.)

1885. Ormerod, Richard Oliver, 35 Philbeach Gardens, South Kensington, London, S.W.

1867. Oughterson, George Blake, care of Peter Brotherhood, Belvedere Road, Lambeth, London, S.E.

1889. Owen, Thomas, Midland Railway, Derby.

1868. Paget, Arthur, Loughborough.

1877. Panton, William Henry, Messrs. Dorman Long and Co., Middlesbrough.

1872. Parker, Thomas, Gorton House, Gorton, near Manchester.

1888. Parker, Thomas, Jun., Carriage and Wagon Superintendent, Manchester Sheffield and Lincolnshire Railway, Gorton, near Manchester; and Gorton House, Gorton, near Manchester.

1891. Parker, Thomas, F.R.S.E., Manor House, Tettenhall, Wolverhampton. [*Parker, Tettenhall.*]

1871. Parkes, Persehouse, Messrs. Persehouse Parkes and Co., 21 Drury Buildings, 21 Water Street, Liverpool. [*Fibrous, Liverpool.*]

1895. Parkinson, Hudson Clough, Engineer's Office, Cumberland Basin, Bristol Docks, Bristol.

1884. Parlane, William, Manager, Hong Kong Ice Company, Hong Kong, China: (or Ladyton Cottage, Bonhill, Dumbartonshire.)

1892. Parratt, William Heather, Enmore Plantation, East Coast, Demerara, British Guiana.

1892. Parrott, Thomas Henry, Messrs. G. E. Belliss and Co., Ledsam Street, Birmingham.

1886. Parry, Alfred, Messrs. Parry and Co., Vulcan Iron Works, Calcutta, India: (or care of Messrs. J. B. Barry and Son, 110 Cannon Street, London, E.C.)

1889. Parry, Evan Henry, care of Wolhuter Gold Mines, P. O. Box 860, Johannesburg, Transvaal, South Africa.

1878. Parsons, The Hon. Richard Clere, Messrs. Bateman Parsons and Bateman, 39 Victoria Street, Westminster, S.W. [*Outfall, London.* 3233.]; and 48 Prince's Gardens, London, S.W.

1886. Passmore, Frank Bailey, Suffolk House, 5 Laurence Pountney Hill, London, E.C. [*Knarf, London.*]

1880. Paterson, Walter Saunders, Bombay Burmah Trading Corporation, Rangoon, British Burmah, India: (or care of Messrs. Wallace Brothers, 8 Austin Friars, London, E.C.)

1877. Paton, John McClure Caldwell, Messrs. Manlove Alliott and Co., Bloomsgrove Works, Ilkeston Road, Nottingham. [*Manloves, Nottingham.*]

1891. Paton, Robert J., Companhia McHardy, Campinas, São Paulo, Brazil.

1881. Patterson, Anthony, Dowlais Iron Works, Cardiff; and 1 Howard Terrace, Howard Gardens, Cardiff.

1883. Pattison, Giovanni, Messrs. C. and T. T. Pattison, Engineering Works, Naples. [*Pattison, Naples.*]

1891. Pattison, Joseph, 123 Bute Street, Cardiff.

1891. Paul, Matthew, Jun., Messrs. Matthew Paul and Co., Levenford Works, Dumbarton.

1891. Paulson, Scott, Box 455, Johannesburg, Transvaal, South Africa: (or care of Dr. Paulson, Mount Sorrel, near Loughborough.)

1872. Paxman, James Noah, Messrs. Davey Paxman and Co., Standard Iron Works, Colchester. [*Paxman, Colchester.*]

1880. Peache, James Courthope, 87 East Hill, Colchester.

1890. Peacock, Francis, Smyrna, Turkey in Asia.

1890. Peacock, James Albert Wells, Smyrna, Turkey in Asia.

1869. Peacock, Ralph, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1873. Pearce, Richard, Carriage and Wagon Superintendent, East Indian Railway, Howrah, Bengal, India.

1894. Pearce, Robert McLardy, care of National Bank of India, 47 Threadneedle Street, London, E.C.

1884. Pearson, Frank Henry, Earle's Shipbuilding and Engineering Works, Hull.

1885. Pearson, Henry William, Engineer, Bristol Water Works, Small Street, Bristol.

1870. Pearson, Thomas Henry, Moss Side Iron Works, Ince, near Wigan.

1888. Peel, Charles Edmund, Quay Parade, Swansea.

1873. Penn, John, M.P., Messrs. John Penn and Sons, Marine Engineers, Greenwich, London, S.E.

1873. Penn, William, Messrs. John Penn and Sons, Marine Engineers, Greenwich, London, S.E.

1874. Pepper, Joseph Ellershaw, Clarence Iron Works, Leeds.

1874. Percy, Cornelius McLeod, King Street, Wigan.

1890. Perry, Weston Alcock, Phosphor-Bronze Co., Birmingham; and Kenwood, St. Peter's Road, Birmingham.

1893. Philip, William Littlejohn, Managing Director, Messrs. Spencer and Co., Melksham Foundry, Melksham.

1881. Philipson, John, Messrs. Atkinson and Philipson, Carriage Manufactory, 27 Pilgrim Street, Newcastle-on-Tyne. [*Carriage, Newcastle-on-Tyne.* 415.]

1885. Phillips, Charles David, Emlyn Engineering Works, Newport, Monmouthshire. [*Machinery, Newport, Mon.*]

1878. Phillips, John, 4 Corona Road, Burnt Ash Hill, Lee, London, S.E.

1885. Phillips, Lionel, Mining Engineer, Bultfontein Diamond Mine, Kimberley, South Africa; and care of H. Eckstein, Box 149, Johannesburg, Transvaal, South Africa.

1879. Phillips, Robert Edward, Royal Courts Chambers, 70 and 72 Chancery Lane, London, W.C.; and 47 Sussex Place, Onslow Gardens, London, S.W. [*Phicycle, London.*]

1890. Phillips, Walter, West India House, Leadenhall Street, London, E.C. [*Philology, London.*]

1882. Phipps, Christopher Edward, Locomotive Superintendent, Madras Railway, Perambore Works, Madras, India.

1894. Pickering, Jonathan, Resident Engineer, Colonial Sugar Refining Co., Sydney, New South Wales; and Broadwater, Richmond River, New South Wales: (or care of John Pickering, 1 Hillend Gardens, Partick Hill, Glasgow.)

1876. Piercy, Henry James Taylor, Messrs. Piercy and Co., Broad Street Engine Works, Birmingham. [*Piercy, Birmingham.* 20.]

1877. Pigot, Thomas Francis, 14 Fitzwilliam Place, Dublin.

1888. Pilkington, Herbert, Wellingborough Iron Works, Wellingborough.

1883. Pillow, Edward, Director of Technical Instruction for Norfolk, Shire Hall, Norwich; and 2 Carlton Terrace, Mill Hill Road, Norwich.

1892. Pinder, Charles Ralph, New Rietfontein Estate and Gold Mines, P. O. Box 897, Johannesburg, Transvaal, South Africa.

1876. Pinel, Charles Louis, Messrs. Lethuillier and Pinel, 26 Rue Méridienne, Rouen, France. [*Lethuillier Pinel, Rouen.*]

1892. Pirie, George, 7 Anglesea Road, Plumstead.

1882. Pirrie, John Sinclair, Austral Otis Elevator and Engineering Works, South Melbourne, Victoria: (or care of Messrs. John Birch and Co., 11 Queen Street Place, London, E.C.)

1888. Pirrie, William James, Messrs. Harland and Wolff, Belfast.

1883. Pitt, Walter, Messrs. Stothert and Pitt, Newark Foundry, Bath. [*Stothert, Bath.*]

1887. Place, John, Linotype Co., 6 Serjeants' Inn, Fleet Street, London, E.C.

1871. Platt, James, Messrs. Fielding and Platt, Atlas Iron Works, Gloucester [*Atlas, Gloucester.*]; and Somerset House, Gloucester. [*Platt, Gloucester.*]

1883. Platt, James Edward, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1867. Platt, Samuel Radcliffe (*Life Member*), Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1878. Platts, John Joseph, Resident Engineer, Odessa Water Works, Odessa, Russia.

1869. Player, John (*Life Member*), Clydach Foundry, near Swansea.

1892. Pogson, Alfred Lee, Engineer-in-Chief, Harbour Trust Board and Works, Madras, India.

1888. Pogson, Joseph, Manager and Engineer, Huddersfield Corporation Tramways, Huddersfield.

1894. Poland, William, Messrs. William Poland and Co., King's Bench Walk, Southwark, London, S.E. [*Determine, London.*]

1893. Pollit, Edward Ernest, Messrs. Pollit and Wigzell, Bank Foundry, Sowerby Bridge.

1894. Pollitt, Harry, Chief Locomotive Engineer, Manchester Sheffield and Lincolnshire Railway, Gorton, Manchester. [*Traction, Gorton.*]

1886. Pollock, James, 22 Billiter Street, London, E.C. [*Specific, London.*]

1876. Pooley, Henry, Messrs. Henry Pooley and Son, Albion Foundry, Liverpool. [*Pooley, Liverpool.*]

1890. Potter, William Henry, Newcastle Chambers, Angel Row, Nottingham.

1864. Potts, Benjamin Langford Foster, 55 Chancery Lane, London, W.C.; and 117 Camberwell Grove, London, S.E.

1878. Powel, Henry Coke, Tintern House, 64 Burnt Ash Hill, Lee, London, S.E.

1874. Powell, Thomas, Brynteg, Neath.

1891. Powles, Henry Handley Pridham, Faraday House, Charing Cross Road, London, W.C.

1867. Pratchitt, John, Messrs. Pratchitt Brothers, Denton Iron Works, Carlisle.

1865. Pratchitt, William, Messrs. Pratchitt Brothers, Denton Iron Works, Carlisle.

1892. Pratt, Middleton, 6 Richmond Terrace, New Brighton, near Birkenhead.

1885. Pratten, William John, Messrs. Harland and Wolff, Belfast.

1890. Preece, William Henry, C.B., F.R.S., General Post Office, St. Martin's-le-Grand, London, E.C.

1882. Presser, Ernest Charles Antoine, Barquillo 26, Madrid.

1877. Price, Henry Sherley, Messrs. Wheatley Kirk, Price, and Goulty, 49 Queen Victoria Street, London, E.C. [*Indices, London.*]

1866. Price, John, 6 Osborne Villas, Jesmond, Newcastle-on-Tyne.

1890. Price, John, Inspecting Engineer, Workington.

1889. Price, John Bennett, Messrs. Charles Macintosh and Co., Cambridge Street, Manchester; and Wyresdale, Wilbraham Road, Chorlton-cum-Hardy, near Manchester.

1859. Price-Williams, Richard, 32 Victoria Street, Westminster, S.W. [*Spandrel, London.*]

1886. Price-Williams, Seymour William, 5 Victoria Street, Westminster, S.W.

1895. Proctor, Charles Faraday, Fittings Department, Edison and Swan Co., Ponders End, London, N.

1894. Pryce, Henry James, Locomotive Superintendent, North London Railway, Bow Road Works, London, E.

1890. Pugh, Charles Henry, Whitworth Works, Rea Street South, Birmingham.

1887. Pullen, William Wade Fitzherbert, Fairley Villa, Oxford Road, Putney, London, S.W.

1884. Puplett, Samuel, 47 Victoria Street, Westminster, S.W.

1866. Putnam, William, Darlington Forge, Darlington.

1887. Pyne, Sir Thomas Salter, C.S.I., care of H.H. the Ameer of Afghanistan, Kabul: (or care of E. C. Clarke, Foreign Office, Government of India, Simla or Calcutta, India: or care of Edmund Neel, C.I.E., India Office, Whitehall, London, S.W.)

1892. Quentrall, Thomas, H.M. Inspector of Mines, Kimberley, South Africa.

1893. Quirk, Edward, Chief Mechanical Engineer, Trinity House, London, E.C.

1870. Radcliffe, William (*Life Member*), Camden House, 25 Collegiate Crescent, Sheffield.

1878. Radford, Richard Heber, 15 St. James' Row, Sheffield. [*Radford, Sheffield.*]

1868. Rafarel, Frederic William, Cwmbran Nut and Bolt Works, near Newport, Monmouthshire.

1884. Rafarel, William Claude, Barnstaple Foundry and Engineering Works, Victoria Road, Barnstaple. [*Rafarel, Barnstaple.*]

1885. Rainforth, William, Britannia Iron Works, Lincoln. [*Rainforths, Lincoln.*]

1878. Rait, Henry Milnes, Messrs. Rait and Gardiner, 155 Fenchurch Street, London, E.C. [*Repairs, London.*]

1892. Ramsay, William, Superintendent Engineer, Scottish Oriental Steamship Co., Hong Kong, China.

1847. Ramsbottom, John, Fernhill, Alderley Edge, Cheshire.

1894. Ramsbottom, John Goodfellow, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1866. Ramsden, Sir James, Abbot's Wood, Barrow-in-Furness; and Reform Chambers, 105 Pall Mall, London, S.W.

1860. Ransome, Allen, 304 King's Road, Chelsea, London, S.W. [*Ransome, London.*]

1886. Ransome, James Edward, Messrs. Ransomes Sims and Jefferies, Orwell Works, Ipswich. [*Ransomes, Ipswich.*]

1873. Rapier, Richard Christopher, Messrs. Ransomes and Rapier, Waterside Iron Works, Ipswich; and 32 Victoria Street, Westminster, S.W. [*Ransomes Rapier, Westminster.*]

1888. Rapley, Frederick Harvey, Messrs. Taite and Carlton, 63 Queen Victoria Street, London, E.C.

1889. Ratcliffe, James Thomas, Baumwoll-Manufactur von Izr. K. Poznanski, Lodz, Russian Poland.

1883. Rathbone, Edgar Philip, Standard Bank Buildings, and P. O. Box 963, Johannesburg, Transvaal, South Africa. [*Viking, Johannesburg.*]

1867. Ratliffe, George, 7A Laurence Pountney Hill, London, E.C.

1893. Raven, Vincent Litchfield, Locomotive Department, North Eastern Railway, Darlington.

1872. Rawlins, John, Manager, Metropolitan Railway-Carriage and Wagon Works, Saltley, Birmingham [*Metro, Birmingham.*]; and The Mount, Erdington, near Birmingham.

1883. Reader, Reuben, Phœnix Works, Cremorne Street, Nottingham.

1887. Readhead, Robert, Messrs. John Readhead and Sons, West Docks, South Shields. [*Readhead, South Shields.* G.P.O. 14. Nat. 2024.]

1882. Reay, Thomas Purvis, Messrs. Kitson and Co., Airedale Foundry, Leeds.

1895. Redit, David, Downham Market, Norfolk.

1881. Redpath, Francis Robert, Canada Sugar Refinery, Montreal, Canada. [*Redpath, Montreal.*]

1883. Reed, Alexander Henry, 64 Mark Lane, London, E.C. [*Wagon, London.*]

1870. Reed, Sir Edward James, K.C.B., F.R.S., Broadway Chambers, Westminster, S.W. [*Carnage, London.*]

1894. Reed, Joseph William, Manager, Engine Works Department, Palmer's Shipbuilding and Iron Works, Jarrow.

1891. Reed, Thomas Alfred, Bute Docks, Cardiff. [*Steam, Cardiff.* 171.]

1884. Rees, William Thomas, Mining Engineer, Maesyffynon, Aberdare.

1891. Reid, Hugh (*Life Member*), Messrs. Neilson and Co., Hyde Park Locomotive Works, Glasgow.

1889. Rendell, Alan Wood, Locomotive Superintendent, East Indian Railway, Jamalpur, Bengal, India: (or 21A Goldhurst Terrace, South Hampstead, London, N.W.)

1890. Rendell, Samuel, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester; and New Mills, near Stockport.

1859. Rennie, George Banks, 20 Lowndes Street, Lowndes Square, London, S.W.

1879. Rennie, John Keith, 49 Queen's Gate, London, S.W.

1881. Rennoldson, Joseph Middleton, Marine Engine Works, South Shields. [*Rennoldson, South Shields.* 11.]

1876. Restler, James William, Engineer, Southwark and Vauxhall Water Works, Southwark Bridge Road, London, S.E.

1883. Rennert, Theodore (*Life Member*), Box 209, Kimberley, South Africa; Box 92, Johannesburg, Transvaal, South Africa: (or care of Messrs. Findlay, Durham and Brodie, 43–46 Threadneedle Street, London, E.C.)

1895. Rew, James Henry, Works Manager, Govan Tube Works, Helen Street, Govan, Glasgow.

1862. Reynolds, Edward, Messrs. Vickers Sons and Co., River Don Works, Sheffield.

1879. Reynolds, George Bernard, Manager, Warora Colliery, Warora, Central Provinces, India: (or care of Messrs. Grindlay and Co., 55 Parliament Street, Westminster, S.W.)

1890. Rice, Thomas Sydney, Aldermary House, 60 Watling Street, London, E.C. [*Ricto, London.*]

1866. Richards, Edward Windsor, Low Moor Iron Works, near Bradford.

1884. Richards, Lewis, Bedlinog Hall, Bedlinog, Treharris, R.S.O., Glamorganshire.

1895. Richardson, Andrew, Messrs. Riley, Hargreaves and Co., Singapore, Straits Settlements: (or care of John R. Allan, 93 Hope Street, Glasgow.)

1892. Richardson, Harry Alfred, Messrs. Hick Hargreaves and Co., Soho Iron Works, Crook Street, Bolton.

1865. Richardson, John, Methley Park, near Leeds.

1873. Richardson, John, Messrs. Robey and Co., Globe Iron Works, Lincoln.

1891. Richardson, John Scott, Box 13, Royal Exchange, Glasgow: (or care of J. W. Champness Richardson, Lindum, 23 Coleridge Road, Crouch End, London, N.)

1887. Richardson, Thomas, M.P., Messrs. T. Richardson and Sons, Hartlepool Engine Works, Hartlepool.

1874. Riches, Tom Hurry, Locomotive Superintendent, Taff Vale Railway, Cardiff. [*Locomotive, Cardiff.*]

1873. Rickaby, Alfred Austin, Bloomfield Engine Works, Sunderland. [*Rickaby, Sunderland.*]

1879. Ridley, James Cartmell, Swalwell Steel Works, Newcastle-on-Tyne.

1893. Ridley, James Taylor, 6 Ruthin Gardens, Cardiff.

1887. Riekie, John, District Locomotive Superintendent, North Western Railway, Quetta, Beluchistan, India.

1874. Riley, James, General Manager, Glasgow Iron and Steel Company, 36 St. Vincent Place, Glasgow. [*Ingot, Glasgow.* 825.]

1894. Riley, Joseph Hacking, Elton Iron Works, Bury, Lancashire.

1885. Ripley, Philip Edward, Messrs. Ransomes Sims and Jefferies, Orwell Works, Ipswich.

1884. Ripper, William, Professor of Mechanical Engineering, The Technical School, St. George's Square, Sheffield.

1879. Rixom, Alfred John, 108 Park Road, Loughborough.

1891. Roberts, Hugh Jorwerth, Messrs. Burn and Co., Howrah Iron Works, Howrah, Calcutta, India: (or care of R. P. Roberts, 3 Osborne Road, Liscard, near Liverpool.)

1887. Roberts, Thomas, Locomotive Engineer, Government Railways, Adelaide, South Australia.

1879. Roberts, Thomas Herbert, Mechanical Superintendent, Chicago and Grand Trunk Railway, Detroit, Michigan, United States.

1887. Roberts, William, 13 Craven Hill Gardens, Hyde Park, London, W.

1879. Robertson, William, Newlyn, Eton Avenue, Hampstead, London, N.W.

1894. Robinson, Arthur Maurice, Messrs. Thomas Robinson and Son, Railway Works, Rochdale. [*Robinson, Rochdale.*]

1894. Robinson, Charles John, Messrs. Thomas Robinson and Son, Railway Works, Rochdale. [*Robinson, Rochdale.*]

1890. Robinson, Frederick Arthur, Messrs. F. A. Robinson and Co., 54 Old Broad Street, London, E.C. [*Farrago, London.*]

1874. Robinson, Henry, Professor of Civil Engineering, King's College, Strand, London, W.C.; and 13 Victoria Street, Westminster, S.W.

1895. Robinson, James, Messrs. T. Richardson and Sons, Hartlepool Engine Works, Hartlepool.

1859. Robinson, John, Messrs. Sharp Stewart and Co., Atlas Works, Glasgow; and Westwood Hall, near Leek.

1886. Robinson, John, 8 Vicarage Terrace, Kendal.

1878. Robinson, John Frederick, Messrs. Sharp Stewart and Co., Atlas Works, Glasgow. [*Loco, Glasgow.* 3210.]

1891. Robinson, John George, Locomotive and Carriage Engineer, Waterford and Limerick Railway, Limerick.

1892. Robinson, Leslie Stephen, 28 Victoria Street, Westminster, S.W. [*Eyebolts, London.*]

1894. Robinson, Mark Heaton, Messrs. Willans and Robinson, Ferry Works, Thames Ditton [*Willans, Thames-Ditton.*]; and Chatley, Fassett Road, Kingston-on-Thames.

1890. Robinson, Sydney Jessop, Messrs. W. Jessop and Sons, Brightside Steel Works, Sheffield.

1878. Robinson, Thomas Neild, Messrs. Thomas Robinson and Son, Railway Works, Rochdale. [*Robinson, Rochdale.*]

1895. Robinson, William, Professor of Mechanical and Electrical Engineering, University College, Nottingham.

1891. Roche, Francis James, care of W. F. Stock, Glenelg, South Australia.

1890. Rochford, John, Commissioners of Irish Lights, Westmoreland Street, Dublin.

1888. Rock, John William, Exchange Corner, Pitt Street, Sydney, New South Wales: (or care of E. G. Rock, The Red House, Ingatestone.)

1872. Rofe, Henry, 8 Victoria Street, Westminster, S.W.

1885. Rogers, Henry John, Watford Engineering Works, Watford. [*Engineer, Watford.*]

1887. Rogers, Horace Wyon, 43 Upper Thames Street, London, E.C.

1892. Ronald, Henry, Small Arms Ammunition Factory, Dum Dum, near Calcutta, India.

1889. Rosenthal, James Hermann, Babcock and Wilcox Co., 147 Queen Victoria Street, London, E.C.

1881. Ross, William, Messrs. Ross and Walpole, North Wall Iron Works, Dublin. [*Iron, Dublin.* 311.]

1893. Rounthwaite, Henry Morrison, Messrs. Maudslay Sons and Field, 110 Westminster Bridge Road, London, S.E.; and 15 Nicosia Road, Wandsworth Common, London, S.W.

1856. Rouse, Frederick, Locomotive Department, Great Northern Railway, Peterborough.

1878. Routh, William Pole, Sutton Court, Sutton, Surrey.

1888. Rowan, James, Messrs. David Rowan and Son, Elliot Street, Glasgow.

1892. Rowe, Almond, Senior Government Marine Surveyor, Singapore, Straits Settlements.

1891. Rowland, Bartholomew Richmond, Messrs. Luke and Spencer, Broadheath, near Manchester.

1867. Ruston, Joseph, Messrs. Ruston Proctor and Co., Sheaf Iron Works, Lincoln; and 6 Onslow Gardens, South Kensington, London, S.W. [*Ruston, Lincoln.*]

1884. Rutherford, George, Managing Director, Mercantile Pontoon Co., Roath Dock, Cardiff. [*Mercantile, Cardiff.* G.P.O. 33; Nat. 30.]

1885. Ryan, John, D.Sc., Professor of Physics and Engineering, University College, Bristol.

1866. Ryland, Frederick, Messrs. A. Kenrick and Sons, Spon Lane, Westbromwich.

1866. Sacré, Alfred Louis, 60 Queen Victoria Street, London, E.C. [*Sextant, London.* 1668.]

1864. Saïd, Marshal M., Pasha, Engineer, Turkish Service, Constantinople: (or care of J. C. Frank Lee, 6 Great Winchester Street, London, E.C.)

1892. Sainsbury, Francis Charles Barrett, Messrs. John Jameson and Son, Bow Street Distillery, Dublin.

1859. Salt, George, 8 Welbeck Street, Cavendish Square, London, W.

1874. Sampson, James Lyons, Messrs. David Hart and Co., North London Iron Works, Wenlock Road, City Road, London, N. [*Bascule, London.* 6699.]

1865. Samuelson, The Right Hon. Sir Bernhard, Bart., F.R.S., Britannia Iron Works, Banbury; 56 Prince's Gate, South Kensington, London, S.W.; and Lupton, Brixham, South Devon.

1881. Samuelson, Ernest, Messrs. Samuelson and Co., Britannia Iron Works, Banbury.

1890. Sandberg, Christer Peter, 19 Great George Street, Westminster, S.W.

1881. Sanders, Henry Conrad, Messrs. H. G. Sanders and Son, Victoria Works, Victoria Gardens, Notting Hill Gate, London, W.; and Elm Lodge, Southall.

1871. Sanders, Richard David, Hartfield House, Eastbourne.

1886. Sandford, Horatio, Messrs. E. A. and H. Sandford, Thames Iron Works, Gravesend.

1881. Sandiford, Charles, Locomotive and Carriage Superintendent, North Western Railway, Lahore, Punjaub, India.

1891. Sands, Harold, Craythorne, Tenterden, Ashford, Kent.

1894. Sankey, Captain Matthew Henry Phineas Riall, Messrs. Willans and Robinson, Ferry Works, Thames Ditton. [*Willans, Thames-Ditton.*]

1874. Sauvée, Albert, 22 Parliament Street, Westminster, S.W. [*Sovez, London.* 3133.]

1891. Savill, Arthur Slater, Exhaust Steam Injector Company, 4 St. Ann's Square, Manchester.

1880. Saxby, John, Messrs. Saxby and Farmer, Railway Signal Works, Canterbury Road, Kilburn, London, N.W. [*Signalmen, London.* 7068.]; and North Court, Hassocks, R.S.O., Sussex.

1893. Saxon, Alfred, Openshaw Engineering Works, Manchester. [*Saxons, Openshaw.* 959.]

1894. Saxon, George, Openshaw Engineering Works, Manchester. [*Saxons, Openshaw.* 959.]

1894. Saxon, James, Openshaw Engineering Works, Manchester. [*Saxons, Openshaw.* 959.]

1869. Scarlett, James, Messrs. E. Green and Son, 2 Exchange Street, Manchester; and Stamford Road, Bowdon, R.O., near Altrincham.

1890. Schofield, George Andrew, General Manager, Sicilian Railways, Palazzo Brijuccia, Palermo, Sicily: (or care of I. D. Schofield, Oakfield, Alderley Edge, Cheshire.)

1886. Scholes, William Henry, 1255 n/n Rivadavia, Buenos Aires, Argentine Republic: (or care of George Scholes, Orwell House, Upton Manor, Plaistow, London, E.)

1883. Schönheyder, William, 4 Rosebery Road, Brixton, London, S.W. [*Schönheyder, London.*]

1880. Schram, Richard, 17A Great George Street, Westminster, S.W. [*Schram, London.*]

1890. Schroller, William, 13 Old Elvet, Durham. [*Balumatari, Durham.*]
1886. Schurr, Albert Ebenezer, Messrs. Fry Miers and Co., Suffolk House, 5 Laurence Pountney Hill, London, E.C.
1885. Scorgie, James, Professor of Applied Mechanics, Civil Engineering College, Poona, India : Poona Villa, Beechgrove Terrace, Aberdeen : (or care of Messrs. W. Watson and Co., 27 Leadenhall Street, London, E.C.)
1891. Scott, Arthur Forbes, 67 Swan Arcade, Bradford.
1882. Scott, Charles Herbert, Messrs. Summers and Scott, High Orchard Iron Works, Gloucester.
1890. Scott, Frederick McClure, 89 Victoria Street, Liverpool.
1891. Scott, F. Walter, Messrs. George Scott and Son, 44 and 46 Christian Street, London, E. [*Thirty-four, London.* 4390.]
1875. Scott, Frederick Whitaker, Atlas Steel and Iron Wire Rope Works, Reddish, Stockport. [*Atlas, Reddish.*]
1891. Scott, Henry John, Glendon Engine Works, Kettering. [*Engine, Kettering.*]
1881. Scott, James, Transvaal Estates and Development Co., Mary Vale Estate, Amsterdam, Transvaal, South Africa : (or Douglasfield, Murthly, Perthshire.)
1886. Scott, James, Consett Iron Works, Consett, R.S.O., County Durham.
1894. Scott, Robert, H. M. Mint, Calcutta, India.
1891. Scott, Robert Julian, Professor of Engineering, New Zealand University, Canterbury College, Christchurch, New Zealand.
1861. Scott, Walter Henry, Great Western of Brazil Railway, Pernambuco, Brazil : (or care of H. Eaton, 75 Tulse Hill, London, S.W.)
1884. Scott-Moncrieff, William Dundas, 14 Victoria Street, Westminster, S.W.
1882. Seabrook, Alfred William, Engineer Surveyor to the Port of Bombay, Port Office, Bombay, India.
1892. Seaman, Charles Joseph, Stockton Forge Works, Stockton-on-Tees. [*Forge, Stockton-on-Tees.*]
1882. Seaton, Albert Edward, Earle's Shipbuilding and Engineering Works, Hull.
1886. Seddon, Robert Barlow, Hall Lane, Hindley, near Wigan.
1891. Selby, Millin, 14 Rue de la Gare, Lille, France.
1882. Selfe, Norman, 279 George Street, Sydney, New South Wales.
1884. Sellers, Coleman, E.D., Professor of Engineering, Stevens Institute, and Franklin Institute; 3301 Baring Street, Philadelphia, Pennsylvania, United States.
1865. Sellers, William, Pennsylvania Avenue, Philadelphia, Pennsylvania, United States.
1891. Sellier, Alphonse Louis, 74 St. James' Street, Sanfernando, Trinidad.

1894. Seymour, Louis Irving, 43 Threadneedle Street, London, E.C. [*Nioga, London.* 11,168.]

1883. Shackleford, Arthur Lewis, General Manager, Britannia Railway-Carriage and Wagon Works, Saltley, Birmingham.

1884. Shackleford, William Copley, Manager, Lancaster Wagon Works, Lancaster; and 6 Victoria Street, Westminster, S.W.

1894. Shand, John, Messrs. Bertrams, St. Katherine's Works, Sciennes, Edinburgh.

1872. Shanks, Arthur, Fairmile, Cobham, Surrey.

1884. Shanks, William, Messrs. Thomas Shanks and Co., Johnstone, near Glasgow. [*Shanks, Johnstone.*]

1881. Shapton, William, Sir William G. Armstrong, Mitchell and Co., 8 Great George Street, Westminster, S.W.

1891. Sharp, Henry, 23 College Hill, London, E.C.; and 1 Whitehall Gardens, London, S.W.

1895. Sharp, John Hutchinson, Messrs. Sharp, Stewart and Co., Atlas Works, Glasgow.

1875. Sharp, Thomas Budworth, Consulting Engineer, Muntz Metal Works, Birmingham; and County Chambers A, Martineau Street, Birmingham. [*Budworth, Birmingham.*]

1881. Shaw, Joshua, Messrs. John Shaw and Sons, Wellington Street Works, Salford, Manchester.

1890. Sheldon, Harry Cecil, Messrs. Boult and Wade, 63 Long Row, Nottingham. [*Boult, Nottingham.* 645.]

1891. Shenton, James, Messrs. Tinker Shenton and Co., Hyde Boiler Works, Hyde, near Manchester.

1892. Shepherd, James, Messrs. Joshua Buckton and Co., Well House Foundry, Meadow Road, Leeds.

1861. Shepherd, John, 45 Regent Park Terrace, Headingley, Leeds.

1875. Sheppard, Herbert Gurney, Chief Engineer, Assioot-Girgeh Railway, Assioot, Upper Egypt: (or 89 Westbourne Terrace, Hyde Park, London, W.)

1876. Shield, Henry, Messrs. Fawcett Preston and Co., Phœnix Foundry, 17 York Street, Liverpool.

1888. Shin, Tsuneta, Director, Ishikawajima Shipbuilding and Engineering Co., Tokyo, Japan.

1892. Shirlaw, Andrew, Suffolk Works, Oozells Street, Birmingham. [*Shirlaw, Birmingham.*]

1889. Shone, Isaac, 47 Victoria Street, Westminster, S.W.

1890. Shoosmith, Harry, 52 Mark Lane, London, E.C.

1890. Shore, Alfred Thomas, Government Inspector of Steam Boilers, Custom House, Bombay, India.

1893. Shroff, Adurjee Burjorjee, Chief Engineer, Sassoon Spinning Mills, Bombay, India.

1885. Shuttleworth, Alfred, Messrs. Clayton and Shuttleworth, Stamp End Works, Lincoln. [*Claytons, Lincoln.*]

1885. Shuttleworth, Major Frank, Messrs. Clayton and Shuttleworth, Stamp End Works, Lincoln; and Old Warden Park, Biggleswade. [*Claytons, Lincoln.*]

1891. Siemens, Alexander (*Life Member*), 12 Queen Anne's Gate, Westminster, S.W.

1871. Simon, Henry, 20 Mount Street, Manchester. [*Reform, Manchester.*]

1877. Simonds, William Turner (*Life Member*), Messrs. J. C. Simonds and Son, Oil Mills, Boston.

1876. Simpson, Arthur Telford, Engineer, Chelsea Water Works, 38 Parliament Street, Westminster, S.W.

1883. Simpson, Charles Liddell, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W. [*Aquosity, London.*]

1885. Simpson, James Thomas, Executive Engineer, Henzada Division, Henzada, Burma.

1882. Simpson, John Harwood, 1 Hargwyne Street, Brixton, London, S.W.

1889. Sinclair, Nisbet, 11 Randolph Gardens, Crow Road, Partick, Glasgow.

1847. Sinclair, Robert, care of Messrs. Sinclair Hamilton and Co., 17 St. Helen's Place, Bishopsgate Street, London, E.C. [*Sinclair, London.*]

1891. Sinclair, Russell, Messrs. J. Wildridge and Sinclair, 97 Pitt Street, Sydney, New South Wales.

1881. Sisson, William, Quay Street Iron Works, Gloucester. [*Sisson, Gloucester.*]

1872. Slater, Alfred, Gloucester Wagon Works, Gloucester.

1892. Slight, George Henry, Sub-Director of Lighthouses, Valparaiso, Chile: (or care of George H. Slight, Sen., Brook Cottage, Ashburton, Devonshire.)

1885. Slight, William Hooper, Messrs. W. Henderson and Co., Soerabaya, Java: (or care of G. H. Slight, 64 Cromwell Road, Fitzhugh, Southampton.)

1891. Sloan, Robert Alexander, Messrs. Sloan and Lloyd Barnes, Castle Chambers, 26 Castle Street, Liverpool. [*Technical, Liverpool.*]

1886. Small, James Miln, Messrs. Urquhart and Small, 17 Victoria Street, Westminster, S.W.

1889. Smelt, John Dann, Argentine Great Western Railway, 4 Finsbury Circus, London, E.C.

1879. Smith, Charles Hubert, Board of Trade Surveyors' Office, Leith.

1860. Smith, Henry, Messrs. Hill and Smith, Brierley Hill Iron Works, Brierley Hill; and Summerhill, Kingswinford, near Dudley. [*Fencing, Brierley Hill.*]

1881. Smith, Henry, Messrs. Simpson and Co., 101 Grosvenor Road, Pimlico, London, S.W.

1860. Smith, Sir John, Parkfield, Duffield Road, Derby.

1876. Smith, John, Wintoun Terrace, Rochdale.

1893. Smith, John, Salford Works, Richard Street, Birmingham. [*Profiler. Birmingham.* 2540.]

1883. Smith, John Bagnold, Newstead Colliery, near Nottingham.

1891. Smith, John Reney, Messrs. Harvey and Bower, 16 Seaton Buildings, 17 Water Street, Liverpool. [*Inspecting, Liverpool.* 6204.]

1890. Smith, John Windle, Messrs. Thomas Drysdale and Co., 438 Calle Moreno, Buenos Aires, Argentine Republic: (or care of Edward Smith, The "Lock," Gainsborough.)

1870. Smith, Michael Holroyd, Royal Insurance Buildings, Crossley Street, Halifax; and 47 Victoria Street, Westminster, S.W. [*Outfall, London.*]

1886. Smith, Reginald Arthur, Messrs. Dorman and Smith, Ordsal Station Electrical Works, Salford, Manchester.

1881. Smith, Robert Henry, Professor of Engineering, Mason Science College, Birmingham; and 124 Hagley Road, Edgbaston, Birmingham.

1885. Smith, Thomas, Steam Crane Works, Old Foundry, Rodley, near Leeds. [*Tomsmith, Leeds.*]

1890. Smith, Thomas Ridsdill, Messrs. Yates and Thom, Canal Foundry, Blackburn.

1881. Smith, Wasteneys, 59 Sandhill, Newcastle-on-Tyne. [*Wasteneys Smith, Newcastle-on-Tyne.* 429.]

1890. Smith, William, London and Manchester Plate Glass Co., Sutton, St. Helen's, Lancashire.

1894. Smith, William, Roads Bridges and Sewerage Department, Sewerage Construction Branch, Public Works Office, Sydney, New South Wales.

1863. Smith, William Ford, Messrs. Smith and Coventry, Gresley Iron Works, Ordsal Lane, Salford, Manchester. [*Gresley, Manchester.* 564.]

1887. Smith, William Mark, District Locomotive Carriage and Wagon Superintendent, Great Southern and Western Railway, Cork.

1882. Smyth, James Josiah, Messrs. James Smyth and Sons, Peasenhall, Suffolk.

1884. Smyth, William Stopford, Engineer, Alexandra Docks, Newport, Monmouthshire.

1883. Snelus, George James, F.R.S., Ennerdale Hall, Frizington, near Carnforth.

1885. Snowdon, John Armstrong, Stanners Closes Steel Works, Wolsingham, near Darlington.

1895. Somers, Walter, Haywood Forge, Halesowen, near Birmingham.

1887. Sorabji, Shapurji, Messrs. Shapurjee and Ratanshaw, 1 and 2 West India House, Leadenhall Street, London, E.C.

1889. Souter-Robertson, David, Assistant Superintendent, Government Canal Foundry and Workshops, Roorkee, North Western Provinces, India.

1885. Southwell, Frederick Charles, Messrs. Richard Hornsby and Sons, Spittlegate Iron Works, Grantham.

1877. Soyres. Francis Johnstone de, 6 Oakfield Road, Clifton, Bristol.

1893. Spence, Arthur William, Manager, Cork Street Foundry and Engineering Works, Dublin.

1887. Spence, William, Cork Street Foundry and Engineering Works, Dublin.

1887. Spencer, Alexander, Messrs. George Spencer, Moulton and Co., 77 Cannon Street, London, E.C. [*George Spencer, London.*]

1878. Spencer, Alfred G., Messrs. George Spencer, Moulton and Co., 77 Cannon Street, London, E.C. [*George Spencer, London.*]

1892. Spencer, Henry Bath, 91 Haworth's Buildings, Cross Street, Manchester. [*Concentration, Manchester.*]

1877. Spencer, John, Globe Tube Works, Wednesbury; and 14 Great St. Thomas Apostle, London, E.C. [*Tubes, Wednesbury. Tubes, London.* 6504.]

1867. Spencer, John W., Newburn Steel Works, Newcastle-on-Tyne. [*Newburn, Newcastle-on-Tyne.*]

1885. Spencer, Mountford, Messrs. Luke and Spencer, Broadheath, near Manchester; and The Hill, Teignmouth.

1854. Spencer, Thomas, Newburn Steel Works, Newcastle-on-Tyne. [*Newburn, Newcastle-on-Tyne.*]

1891. Spencer, William, Messrs. James Spencer and Co., Chamber Iron Works, Hollinwood, near Manchester.

1885. Spooner, George Percival, Locomotive Superintendent, Bolan Railway, Hirokh, Beluchistan, India; and Whitehall Club, Parliament Street, Westminster, S.W.

1883. Spooner, Henry John, 309 Regent Street, London, W.

1895. Sprague, Ernest Headly, Engineering Laboratory, University College, Gower Street, London, W.C.

1869. Stabler, James, 13 Effra Road, Brixton, London, S.W.

1877. Stanger, George Hurst, Queen's Chambers, North Street, Wolverhampton.

1875. Stanger, William Harry, Chemical Laboratory and Testing Works, Broadway, Westminster, S.W. [3117.]

1888. Stanley, Harry Frank, Messrs. H. Pontifex and Sons, Farringdon Works, Shoe Lane, London, E.C.; and 84 Finsbury Park Road, London, N.

1888. Stannah, Joseph, 20 Southwark Bridge Road, London, S.E.

1884. Stanton, Frederic Barry, 18 Bishopsgate Street Within, London, E.C.

1874. Stephens, Michael, Chief Locomotive Superintendent of the Government Railways, Cape Town, Cape of Good Hope.

1868. Stephenson, George Robert, Ben Braich, Tilehurst Road, Reading.

1879. Stephenson, Joseph Gurdon Leycester, 6 Drapers' Gardens, London, E.C. [*Fluvius, London.*]

1888. Stephenson-Peach, William John, Askew Hill, Repton, Burton-on-Trent.

1876. Sterne, Louis, Messrs. L. Sterne and Co., Crown Iron Works, Glasgow [*Crown, Glasgow.*]; and 28 Victoria Street, Westminster, S.W. [*Elsterne, London.* 3066.]

1891. Stevens, James, 9 and 11 Fenchurch Avenue, London, E.C.

1894. Stevens, Thomas, 37 and 38 Mark Lane, London, E.C.

1887. Stevenson, David Alan, F.R.S.E., 84 George Street, Edinburgh.

1892. Stevinson, Thomas, Messrs. Hender and Stevinson, Nailsworth, near Stroud, Gloucestershire.

1893. Steward, George Richard, 15 Queen Street, Queen Victoria Street, London, E.C.

1887. Stewart, Andrew, 41 Oswald Street, Glasgow.

1878. Stewart, Duncan, Messrs. Duncan Stewart and Co., London Road Iron Works, Glasgow. [*Stewart, Glasgow.* 531.]

1851. Stewart, John, Blackwall Iron Works, Poplar, London, E. [*Steamships, London.*]; and Egerton Lodge, Queen's Road, Tunbridge Wells.

1888. Stiff, William Charles, 75 Hagley Road, Edgbaston, Birmingham.

1892. Still, William Henry, Hudjuff, Aden, Arabia.

1880. Stirling, James, Locomotive Superintendent, South Eastern Railway, Ashford, Kent.

1885. Stirling, Matthew, Locomotive Superintendent, Hull Barnsley and West Riding Junction Railway and Dock Co., Hull.

1867. Stirling, Patrick, Locomotive Superintendent, Great Northern Railway, Doncaster.

1888. Stirling, Robert, Locomotive Department, North Eastern Railway, Gateshead.

1875. Stoker, Frederick William, 6 Consolidated Gold Fields Buildings, P.O. Box 353, Johannesburg, Transvaal, South Africa.

1877. Stokes, Alfred Allen, Beaumont, Cheltenham.

1892. Stone, Edward Herbert, District Engineer, East Indian Railway, Asansol, India.

1887. Stone, Frank Holmes, 363 Oxford Road, Manchester.

1877. Stothert, George Kelson, Steam Ship Works, Bristol.

1888. Strachan, James, 70 Frederick Street, Gray's Inn Road, London, W.C.

1892. Strachan, John, 29 The Walk, Cardiff.

1888. Straker, Sidney, Messrs. Straker Whitworth and Co., 139 Cannon Street, London, E.C. [*Rhomboidal, London.*]; and 210 Stanstead Road, Forest Hill, London, S.E.

1895. Stromeyer, Johann Philipp Edmond Charles, Lloyd's Register of British and Foreign Shipping, 312 Argyle Street, Glasgow.

1884. Stronge, Charles, Locomotive Department, Porto Alegre and New Hamburg Railway, São Leopoldo, Rio Grande do Sol, Brazil: (or 1 Albion Street, Hyde Park, London, W.)

1873. Strype, William George, 115 Grafton Street, Dublin. [*Strype, Dublin.*]

1890. Stutzer, Waldemar, Koltchugin Brass and Copper Mill Co., Alexandrov Station, Jaroslav Railroad, Russia.

1882. Sugden, Thomas, Babcock and Wilcox Co., 147 Queen Victoria Street, London, E.C.

1890. Sulzer, Jacob, Messrs. Sulzer Brothers, Winterthur, Switzerland.

1861. Sumner, William, 2 Brazennose Street, Manchester.

1875. Sutcliffe, Frederic John Ramsbottom, Engineer, Low Moor Iron Works, near Bradford.

1883. Sutton, Joseph Walker, 36 Bedford Street, Strand, London, W.C.

1880. Sutton, Thomas, Carriage and Wagon Superintendent, Furness Railway, Barrow-in-Furness.

1882. Swaine, John, 9 Miles Road, Clifton, Bristol.

1884. Swan, Joseph Wilson, F.R.S., 57 Holborn Viaduct, London, E.C.; and 58 Holland Park, London, W.

1882. Swinburne, Mark William, Wallsend Brass Works, Newcastle-on-Tyne; and 117 Park Road, Newcastle-on-Tyne. [*Bronze, Wallsend.*]

1864. Swindell, James Swindell Evers, Homer Hill, Cradley, Staffordshire.

1890. Swinerd, Edward, Superintendent, Locomotive Carriage and Wagon Departments, Mogyana Railway, Campinas, Brazil: (or care of Messrs. Fry Miers and Co., Suffolk House, Laurence Pountney Hill, London, E.C.)

1890. Swinnerton, Robert Allen William, Executive Engineer, Public Works Department, Bolarum, Dekkan, India: (or care of Messrs. Henry S. King and Co., 65 Cornhill, London, E.C.)

1878. Taite, John Charles, Messrs. Taite and Carlton, 63 Queen Victoria Street, London, E.C. [1618.]; and The Corner House, Shortlands, S.O., Kent.

1875. Tangye, George, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham. [*Tangyes, Birmingham.*]

1889. Tangye, Harold Lincoln, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham.

1861. Tangye, James, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham; and Aviary Cottage, Illogan, near Redruth.

1895. Tannett, John Croysdale, Messrs. Fullerton, Hodgart and Barclay, Vulcan Works, Paisley.

1879. Tartt, William, Maythorn, Blindley Heath, Godstone, near Red Hill.

1893. Tasker, Frederick, Messrs. Tasker Sons and Co., New Station Road, Sheffield. [*Tasker, Sheffield.* 1005.]

1876. Taunton, Richard Hobbs, 10 Coleshill Street, Birmingham.

1874. Taylor, Arthur, Manager, Sociedad Anglo-Vasca, Villanueva del Duque, Provincia de Cordoba, Spain: (or 21 Victoria Road, Kensington, London, W.)

1873. Taylor, John, Midland Foundry, Queen's Road, Nottingham.

1875. Taylor, Joseph Samuel, Messrs. Taylor and Challen, Derwent Foundry, 60 and 62 Constitution Hill, Birmingham. [*Derwent, Birmingham.*]

1874. Taylor, Percyvale, Messrs. Burthe and Taylor, Paris; and 21 Victoria Road, Kensington, London, W.

1893. Taylor, Robert, Jun., Works Manager, Messrs. Asa Lees and Co., Soho Iron Works, Oldham.

1882. Taylor, Robert Henry, 2 Winchester Terrace, Newcastle-on-Tyne.

1895. Tebbutt, Sidney, 32 Avenue Road, Leamington.

1864. Tennant, Sir Charles, Bart. (*Life Member*), The Glen, Innerleithen, near Edinburgh.

1882. Terry, Stephen Harding, 17 Victoria Street, Westminster, S.W.

1891. Tetlow, Ernest, Messrs. Tetlow Brothers, Bottoms Iron Works, Hollinwood, near Manchester.

1877. Thom, William, Messrs. Yates and Thom, Canal Foundry, Blackburn.

1889. Thomas, James Donnithorne, 25A Old Broad Street, London, E.C. [*Kooringa, London.*]

1867. Thomas, Joseph Lee, 2 Hanover Terrace, Ladbroke Square, Notting Hill, London, W.

1888. Thomas, Philip Alexander, 35 Queen Victoria Street, London, E.C. [*Argument, London.*]

1864. Thomas, Thomas, 10 Richmond Road, Roath, Cardiff.

1874. Thomas, William Henry, 6 Delahay Street, Westminster, S.W.

1891. Thompson, James, Highfield Boiler Works, Ettingshall, Wolverhampton. [*Boiler, Wolverhampton.*]

1875. Thompson, John, Highfield Boiler Works, Ettingshall, Wolverhampton [*Boiler, Wolverhampton.*]

1883. Thompson, Richard Charles, Messrs. Robert Thompson and Sons, Southwick Shipbuilding Yard, Sunderland.

1887. Thompson, William Phillips, 6 Lord Street, Liverpool.

1875. Thomson, James McIntyre, Glen Tower, Great Western Road, Glasgow.

1868. Thomson, John, 3 Crown Terrace, Dowanhill, Glasgow.

1889. Thomson, Robert McNider, Kobe Engine Works, Kobe, Japan: (or care of William Hipwell, Hillside House, Sharnbrook, Bedford.)

1893. Thornbery, William Henry, Jun., 38 Bennett's Hill, Birmingham. [*Engineer, Birmingham.* 113.]

1868. Thornewill, Robert, Messrs. Thornewill and Warham, Burton Iron Works, Burton-on-Trent.

1885. Thornley, George, Messrs. Buxton and Thornley, Waterloo Engineering Works, Burton-on-Trent.

1877. Thornton, Frederic William, Hull Hydraulic Power Co., Machell Street, Hull.

1882. Thornton, Hawthorn Robert, Lancashire and Yorkshire Railway, Horwich, near Bolton.

1888. Thornton, Robert Samuel, West's Patent Press Co., Etawah, North Western Provinces, India.

1876. Thornycroft, John Isaac, F.R.S., Messrs. John I. Thornycroft and Co., Steam Yacht and Launch Builders, Church Wharf, Chiswick, London, W. [*Thornycroft, London.*]

1882. Thow, William, Locomotive Engineer, New South Wales Government Railways, Eveleigh Workshops, Sydney, New South Wales: (or care of Joseph Meilbek, 13 Victoria Street, Westminster, S.W.)

1891. Tilley, Albert, care of Bernard Dawson, York House, Malvern Link, Malvern.

1885. Timmermans, François, Managing Director, Société anonyme des Ateliers de la Meuse, Liége, Belgium. [*Société Meuse, Liége.*]

1884. Timmis, Illius Augustus, 2 Great George Street, Westminster, S.W. [*Timmis, London.*]

1886. Tipping, Henry, 19 Gloucester Place, Greenwich, London, S.E.

1890. Titley, Arthur, Beechwood, Hartopp Road, Four Oaks, Sutton Coldfield, near Birmingham.

1888. Todd, Robert Ernest, Mechanical Engineer, Tucuman, Estacion Provincia, Argentine Republic: (or care of William H. Todd, County Buildings, Land of Green Ginger, Hull.)

1875. Tomkins, William Steele, Messrs. Sharp Stewart and Co., Atlas Works, Glasgow; and 28 Victoria Street, Westminster, S.W.

1888. Topple, Charles James, Machinery Department, Royal Arsenal, Woolwich.

1894. Touch, John Edward, 34 Victoria Street, Westminster, S.W.

1883. Tower, Beauchamp, 5 Queen Anne's Gate, Westminster, S.W.

1889. Towler, Alfred, Messrs. Hathorn Davey and Co., Sun Foundry, Leeds.

1886. Towne, Henry Robinson, Yale and Towne Manufacturing Co., Stamford, Connecticut, United States.

1893. Townsend, Captain C. Collingwood, R.A., Superintendent, Gun-Carriage Factory, Madras, India.

1890. Trail, John, Marine Superintendent, Knott's Prince Line of Steamers, Newcastle-on-Tyne.

1888. Travis, Henry, Assistant Superintending Engineer and Constructor of Shipping to the War Department, Royal Arsenal, Woolwich.

1889. Treharne, Gwilym Alexander, Pontypridd; and Aberdare.

1889. Trenery, William Penrose, 73 Via Milano, Genoa, Italy.

1883. Trentham, William Henry, 39 Victoria Street, Westminster, S.W.

1876. Trevithick, Richard Francis, Locomotive and Carriage Superintendent, Japanese Government Railways, Kobe, Japan: (or care of Mrs. Mary Trevithick, The Cliff, Penzance.)

1887. Trier, Frank, Messrs. Brunton and Trier, 19 Great George Street, Westminster, S.W.

1885. Trueman, Thomas Brynalyn, 61 Calle Defensores de Buenos Aires, San Fernando, Buenos Aires, Argentine Republic: (or care of Thomas R. Trueman, 3 The Barons, Twickenham.)

1887. Turnbull, Alexander, Messrs. Alexander Turnbull and Co., St. Mungo Works, Bishopbriggs, Glasgow. [*Valve, Glasgow.* 1270.]

1885. Turnbull, John, Jun., 18 Blythswood Square, Glasgow. [*Turbine, Glasgow.* 59.]

1894. Turner, Albert, Whitehouse Machine Works, Denton, near Manchester. [*Machines, Denton.* 5.]

1866. Turner, Frederick, Messrs. E. R. and F. Turner, St. Peter's Iron Works, Ipswich. [*Gippeswyk, Ipswich.*]

1882. Turner, Thomas, Messrs. Andrew Barclay, Sons and Co., Caledonia Works, Kilmarnock. [*Barclayson, Kilmarnock.* 10.]

1886. Turner, Tom Newsum, Vulcan Iron Works, Langley Mill, near Nottingham.

1876. Turney, Sir John, Messrs. Turney Brothers, Trent Bridge Leather Works, Nottingham. [*Turney, Nottingham.*]

1891. Tweddell, Ralph Hart, 14 Delahay Street, Westminster, S.W. [*Tweddell, Westminster, London.*]

1882. Tweedy, John, Messrs. Wigham Richardson and Co., Newcastle-on-Tyne.

1856. Tyler, Sir Henry Whatley, K.C.B., Linden House, Highgate Road, London, N.W.

1889. Tyrrell, Joseph John, Messrs. Clayton and Shuttleworth, Stamp End Iron Works, Lincoln.

1878. Unwin, William Cawthorne, F.R.S., Professor of Engineering, City and Guilds of London Central Institution, Exhibition Road, London, S.W.; and 7 Palace Gate Mansions, Kensington, London, W.

1875. Urquhart, Thomas, Delny House, Delny, R.S.O., Ross-shire.

1880. Valon, William Andrew McIntosh, 140 and 141 Temple Chambers, Temple Avenue, London, E.C.; and Ramsgate. [*Valon, Ramsgate.*]

1895. Van Raalte, Joseph, General Manager, Royal Shipbuilding and Engineering Works, Flushing, Holland. [*Schelde, Flushing.*]

1885. Vaughan, William Henry, Royal Iron Works, West Gorton, Manchester. [*Vaunting, Manchester.* 5106.]

1862. Vavasseur, Josiah, 28 Gravel Lane, Southwark, London, S.E.; and Rothbury, Blackheath Park, London, S.E. [*Exemplar, London.*]

1889. Vesian, John Stuart Ellis de, 5 Crown Court, Cheapside, London, E.C. [*Biceps, London.*]

1891. Vicars, John, Gillbank, Boot, viâ Carnforth.

1865. Vickers, Albert, Messrs. Vickers Sons and Co., River Don Works, Sheffield.

1861. Vickers, Thomas Edward, Messrs. Vickers Sons and Co., River Don Works, Sheffield.

1888. Voysey, Henry Wesley, 1 Fordwych Road, Brondesbury, London, N.W.

1883. Waddell, James, 17 Ashton Terrace, Dowanhill, Glasgow.

1856. Waddington, John, 35 King William Street, London Bridge, London, E.C.

1879. Wadia, The Hon. Nowrosjee Nesserwanjee, C.I.E., Messrs. Nowrosjee Wadia and Sons, Tardeo, Bombay: Bella Vista, Cumballa Hill, Bombay: (or care of Messrs. Hick Hargreaves and Co., Soho Iron Works, Bolton.) [*Wadia, Bombay.*]

1882. Wailes, George Herbert, St. Andrews, Watford, Herts.

1884. Wailes, Thomas Waters, General Manager, Mountstuart Dry Dock and Engineering Works, Cardiff. [*Mountstuart, Cardiff.*]

1888. Waister, William Henry, Assistant Locomotive Superintendent, Great Western Railway, Stafford Road Works, Wolverhampton.

1881. Wake, Henry Hay, Engineer to the River Wear Commission, Sunderland.

1882. Wakefield, William, 123 Rathgar Road, Dublin.

1892. Waldron, Patrick Lawrence, R.N.R., Irish Lights Service, Castletown Berehaven, Co. Cork, Ireland; and 24 St. Joseph's Road, Aughrim Street, Dublin.

1891. Walker, Arthur Tannett, Messrs. Tannett Walker and Co., Goodman Street Works, Hunslet, Leeds.

1875. Walker, George, 95 Leadenhall Street, London, E.C.

1890. Walker, Henry, 11 Oxford Terrace, Gateshead.

1894. Walker, Henry Claude, Messrs. R. Waygood and Co., Falmouth Road, Great Dover Street, London, S.E. [*Waygood, London.* 4760.]

1875. Walker, John Scarisbrick, Messrs. J. S. Walker and Brother, Pagefield Iron Works, Wigan; and 41 Leyland Road, Southport. [*Pagefield, Wigan.*]

1884. Walker, Sydney Ferris, Cardiff Electrical Works, Severn Road, Cardiff [*Dynamo, Cardiff.*]; and Hunter's Forge, New Bridge Street, Newcastle-on-Tyne. [*Dynamo, Newcastle-on-Tyne.*]

1876. Walker, Thomas Ferdinand, Ship's Log Manufacturer, 58 Oxford Street, Birmingham.

1890. Walker, William George, 47 Victoria Street. Westminster, S.W.

1878. Walker, Zaccheus, Jun., Fox Hollies Hall, near Birmingham.

1884. Wallace, John, Backworth Collieries, near Newcastle-on-Tyne.

1895. Wallace, Joseph, Tennant's Agency, San Fernando, Trinidad.

1884. Wallau, Frederick Peter, Messrs. Harland and Wolff, Belfast.

1868. Wallis, Herbert, Mechanical Superintendent, Grand Trunk Railway, Montreal, Canada.

1893. Wallwork, Roughsedge, Union Bridge Iron Works, Charter Street, Manchester.

1891. Walmsley, John, Messrs. J. and P. Coats, Ferguslie Thread Works, Paisley.

1865. Walpole, Thomas, Messrs. Ross and Walpole, North Wall Iron Works, Dublin. [*Iron, Dublin.* 311.]

1877. Walton, James, 28 Maryon Road, Charlton, Kent.

1881. Warburton, John Seaton, 19 Stanwick Road, West Kensington, London, W.

1882. Ward, Thomas Henry, 24 Church Lane, Smethwick, near Birmingham.

1876. Ward, William Meese, Newton Villa, Claremont Road, Handsworth, R.O., near Birmingham.

1864. Warden, Walter Evers, Phœnix Bolt and Nut Works, Handsworth, R.O., near Birmingham. [*Bolts, Birmingham.*]

1882. Wardle, Edwin, Messrs. Manning Wardle and Co., Boyne Engine Works, Hunslet, Leeds. [*Manning, Leeds.*]

1886. Warren, Frank Llewellyn, 73 Breakspears Road, St. John's, London, S.E.

1885. Warren, Henry John, Jun., Cornwall Boiler Works, Camborne.

1885. Warren, William, Chief Engineer, Midland Uruguay Railway, Paysandu, Uruguay: (or care of Walter Ross, Hill Top, Blythe Hill, Catford, London, S.E.)

1889. Warsop, Thomas, Coniston Copper Mines, Coniston, S.O., Lancashire.

1858. Waterhouse, Thomas (*Life Member*), Claremont Place, Sheffield.

1891. Waterous, Julius E., Waterous Engine Works Co., Brantford, Ontario, Canada.

1881. Watkins, Alfred, 58 Fenchurch Street, London, E.C.

1862. Watkins, Richard, 71 Blenheim Crescent, London, W.

1890. Watkinson, William Henry, Professor of Motive Power Engineering, Glasgow and West of Scotland Technical College, 38 Bath Street, Glasgow.

1890. Watson, George Coghlan, Manganese Bronze and Brass Co., St. George's Wharf, Deptford, London, S.E.; and Granville House, Bedford Park, Croydon.

1882. Watson, Henry Burnett, Messrs. Henry Watson and Son, High Bridge Works, Newcastle-on-Tyne. [*Watsons, Newcastle-on-Tyne.* 439.]

1879. Watson, Sir William Renny, 16 Woodlands Terrace, Glasgow.

1891. Watt, Charles, 418 Little Collins Street, Melbourne, Victoria.

1877. Watts, John, Broad Weir Engine Works, Bristol.

1886. Weatherburn, Robert, Locomotive Manager, Midland Railway Works, Kentish Town, London, N.W.

1894. Webb, Henry, Messrs. Joseph Webb and Co., Irwell Forge and Rolling Mills, Bury, Lancashire.

1884. Webb, Richard George, Messrs. Richardson and Cruddas, Byculla Iron Works, Bombay, India: (or care of Messrs. Richardson and Hewett, 101 Leadenhall Street, London, E.C.)

1890. Webster, John James, 39 Victoria Street, Westminster, S.W.

1887. Webster, William, 6 Oxley Road, Singapore, Straits Settlements.

1883. Weck, Friedrich, Lilleshall Old Hall, near Newport, Shropshire.

1891. Weightman, Walter James, Engineer-in-Chief, Nilgiri Railway, Coonoor, Madras, India.

1888. Wellman, Samuel T., Upland, Delaware County, Pennsylvania, United States.

1882. West, Charles Dickinson, Professor of Mechanical Engineering, Imperial College of Engineering, Tokyo, Japan.

1876. West, Henry Hartley, Naval Architect and Engineer, 5 Castle Street, Liverpool. [*Referee, Liverpool.* 5223.]

1894. West, James. Post Office, Koffyfontein Mines, Orange Free State, South Africa.

1894. West, John, Albion Iron Works, Miles Platting, Manchester.

1891. West, Leonard, Ravenhead Plate Glass Works, St. Helen's, Lancashire.

1874. West, Nicholas James, Trevales Mansion, St. Stythians, Perranarworthal, Cornwall.

1877. Western, Charles Robert, Broadway Chambers, Westminster, S.W. [*Donbowes, London.* 3199.]

1877. Western, Maximilian Richard, care of Colonel Western, C.M.G., Broadway Chambers, Westminster, S.W.

1895. Westmacott, Henry Armstrong, Messrs. John Spencer and Sons, Newburn Steel Works, Newcastle-on-Tyne.

1862. Westmacott, Percy Graham Buchanan, Sir W. G. Armstrong Mitchell and Co., Elswick Engine Works, Newcastle-on-Tyne; and Benwell Hill, Newcastle-on-Tyne.

1880. Westmoreland, John William Hudson, Lecturer on Engineering, University College, Nottingham.

1880. Westwood, Joseph, Napier Yard, Millwall, London, E. [*Westwood, London.* 5065.]

1888. Weyman, James Edwardes, Messrs. Weyman and Hitchcock, Trusty Engine Works, Cheltenham; and Chadborne, Christ Church Road, Cheltenham.

1894. Whitby, Arthur George, care of George Whitby, The Limes, Amersham.

1882. White, Alfred Edward, Borough Engineer's Office, Town Hall, Hull.

1887. White, Alfred George, 11 Queen Victoria Street, London, E.C.

1888. White, Sir William Henry, K.C.B., LL.D., F.R.S., Assistant Controller and Director of Naval Construction, Admiralty, Whitehall, London, S.W.

1890. Whitehouse, Edwin Edward Joseph, Monkbridge Iron Works, Leeds.

1876. Whiteley, William, Holly Mount, Edgerton, Huddersfield.

1891. Whittaker, John, Messrs. William Whittaker and Sons, Sun Iron Works, Oldham.

1869. Whittem, Thomas Sibley, Wyken Colliery, Coventry.

1878. Whytehead, Hugh Edward, Meadowside, Mayfield Road, Moseley, Birmingham.

1878. Wicks, Henry, Messrs. Burn and Co., Howrah Iron Works, Howrah, Bengal, India: (or care of John Spencer, 125 West Regent Street, Glasgow.)

1868. Wicksteed, Joseph Hartley, Messrs. Joshua Buckton and Co., Well House Foundry, Meadow Road, Leeds.

1891. Widdowson, John Henry, Britannia Works, Ordsal Lane, Salford, Manchester.

1878. Widmark, Harald Wilhelm, Helsingborgs Mekaniska Verkstad, Helsingborg, Sweden.

1889. Wigham, John Richardson, Messrs. J. Edmundson and Co., Stafford Works, 35 Capel Street, Dublin.

1881. Wigzell, Eustace Ernest, Billiter House, Billiter Street, London, E.C. [*Wigzell, London.* 1844.]

1890. Wild, John, Falcon Iron Works, Oldham. [*Falcon, Oldham.*]

1886. Wildridge, John, Messrs. J. Wildridge and Sinclair, 97 Pitt Street, Sydney, New South Wales: (or care of R. Wildridge, 7 Alexandra Crescent, Newcastle-on-Tyne.)

1890. Wildy, William Lawrence, 42 North Parade, Grantham.

1892. Wilkinson, Edward R., 63 Middle Lane, Hornsey, London, N.

1885. Willcox, Francis William, 45 West Sunniside, Sunderland.

1893. Williams, Arthur Edward, Resident Engineer, Dagenham Dock, Essex.

1883. Williams, Sir Edward Leader, Engineer, Manchester Ship Canal Co., 41 Spring Gardens, Manchester [*Leader, Manchester.* 688.]; and The Oaks, Altrincham.

1884. Williams, John Begby, Central Marine Engine Works, West Hartlepool.

1885. Williams, Nicholas Thomas, General Manager, Witwatersrand Gold Mine, P.O. Box 1019, Johannesburg, Transvaal, South Africa.

1847. Williams, Richard (*Life Member*), Brunswick House, Wednesbury.

1890. Williams, Thomas David, The Lodge, Sedlescombe Road, St. Leonard's-on-Sea.

1881. Williams, William Freke Maxwell, 29 Great St. Helen's, London, E.C. [*Wabash, London.*]

1873. Williams, William Lawrence, 16 Victoria Street, Westminster, S.W. [*Snowdon, London.*]

1889. Williams, William Walton, Jun., Lagos, West Africa.

1883. Williamson, Richard, Messrs. Richard Williamson and Son, Iron Shipbuilding Yard, Workington; and South Lodge, Cockermouth.

1878. Wilson, Alexander, Messrs. Charles Cammell and Co., Cyclops Steel and Iron Works, Sheffield.

1882. Wilson, Alexander Basil, Holywood, Belfast. [*Wilson, Holywood.* 201.]

1884. Wilson, James, Pacha, Chief Engineer of the Daira Sanieh, Egypt: Cairo, Egypt.

1881. Wilson, John, Engineer, Great Eastern Railway, Liverpool Street Station, London, E.C. [*Wilson, Eastern, London.*]

1863. Wilson, John Charles, 39 Victoria Street, Westminster, S.W. [*Palacol, London.*]

1892. Wilson, John Charles Grant, Locomotive Superintendent, Manila Railway, Manila, Philippine Islands.
1879. Wilson, Joseph William, Principal of School of Practical Engineering, Crystal Palace, Sydenham, London, S.E.
1890. Wilson, Joseph William, Jun., Vice-Principal of School of Practical Engineering, Crystal Palace, Sydenham, London, S.E.
1880. Wilson, Robert, 10 St. Bride Street, London, E.C.; and 7 St. Andrew's Place, Regent's Park, London, N.W.
1883. Wilson, Robert, F.R.S.E., 13 Victoria Street, Westminster, S.W.
1890. Wilson, Robert James, care of Thomas Wilson, 5 Ribblesdale Road, Hornsey, London, N.
1891. Wilson, Thomas, Morro Foundry, Iquique, Chile.
1873. Wilson, Thomas Sipling, Messrs. Holroyd Horsfield and Wilson, Larchfield Foundry, Hunslet Road, Leeds.
1888. Wilson, Walter Henry, Messrs. Harland and Wolff, Belfast.
1881. Wilson, Wesley William, Messrs. A. Guinness Son and Co., St. James' Gate Brewery, Dublin.
1891. Wimshurst, James Edgar, Messrs. William Esplen, Son, and Swainston, Billiter Buildings, 22 Billiter Street, London, E.C.
1890. Winder, Charles Aston, Messrs. Winder Brothers, Royds Works, Attercliffe, Sheffield.
1886. Windsor, Edwin Wells, 1 Rue du Hameau des Brouettes, Rouen, France.
1890. Wingfield, Digby Charles, Messrs. E. Beanes and Co., Falcon Works, Hackney Wick, London, N.E.
1887. Winmill, George, Locomotive and Carriage Superintendent, Oudh and Rohilkund Railway, Lucknow, India: (or Harewood, Junction Road, Romford.)
1872. Wise, William Lloyd, 46 Lincoln's Inn Fields, London, W.C. [*Lloyd Wise, London.* 2766.]
1884. Withy, Henry, Messrs. Furness Withy and Co., Middleton Ship Yard, West Hartlepool. [*Withy, West Hartlepool.* 4.]
1878. Wolfe, John Edward, General Manager, Alagoas Railway, Maceio, Brazil: (or care of Rev. Prebendary Wolfe, Arthington, Torquay.)
1878. Wolfenden, Robert, Revenue Cutter "Ling Fêng," care of Commissioner of Customs, Shanghai, China: (or 25 Grafton Street, Moss Side, Manchester.)
1888. Wolff, Gustav William, M.P., Messrs. Harland and Wolff, Belfast.
1881. Wood, Edward Malcolm, 3 Victoria Street, Westminster, S.W.
1887. Wood, Henry, Messrs. John and Edward Wood, Victoria Foundry, Bolton.
1880. Wood, John Mackworth, Engineer's Department, New River Water Works, Clerkenwell, London, E.C.

1868. Wood, Lindsay, Mining Engineer, Southhill, near Chester-le-Street.

1885. Wood, Robert Henry, 15 Bainbrigge Road, Headingley, Leeds.

1884. Wood, Sidney Prescott, Semaphore Iron Works, Newport, Melbourne, Victoria: (or care of H. W. Little, Messrs. McKenzie and Holland, Vulcan Iron Works, Worcester.)

1890. Wood, Thomas Royle, care of Samuel Bash, 1663 Avenida Montes de Oca. Buenos Aires, Argentine Republic: (or care of William Wood, 28 Hyde Grove, Chorlton-on-Medlock, Manchester.)

1890. Wood, William, 200 Tulse Hill, London, S.W.

1882. Woodall, Corbet, Palace Chambers, 9 Bridge Street, Westminster, S.W.

1894. Woods, William Henry, Messrs. Hamilton Woods and Co., Liver Foundry and Engine Works, Ordsal Lane, Salford, Manchester. [*Sluice, Manchester.* 1962.]

1895. Wordingham, Charles Henry, Electric Light Station, Dickinson Street, Manchester.

1887. Worger, Douglas Fitzgerald, Assistant Engineer, Southwark and Vauxhall Water Works, Southwark Bridge Road, London, S.E.

1893. Wormald, Henry, Resident Engineer, Ackton Hall Colliery, Featherstone, near Pontefract.

1874. Worsdell, Thomas William, Stonycroft, Arnside, near Carnforth.

1894. Worsdell, Wilson, Locomotive Superintendent, North Eastern Railway, Gateshead.

1877. Worssam, Henry John, Messrs. G. J. Worssam and Son, Wenlock Road, City Road, London, N. [*Massrow, London.* 6656.]

1886. Worthington, Charles Campbell, Messrs. Henry R. Worthington, Hydraulic Works, 145 Broadway, New York, United States: (or care of the Worthington Pumping Engine Co., 153 Queen Victoria Street, London, E.C.)

1888. Worthington, Edgar, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester; and Mill Bank, Bowdon, near Altrincham.

1860. Worthington, Samuel Barton, Consulting Engineer, 33 Princess Street, Manchester; and Mill Bank, Bowdon, near Altrincham.

1866. Wren, Henry, Messrs. Henry Wren and Co., London Road Iron Works, Manchester. [*Wrens, Manchester.*]

1881. Wrench, John Mervyn, Chief Engineer, Indian Midland Railway, Jhansi, N.W. Provinces, India.

1876. Wright, James, Messrs. Ashmore Benson Pease and Co., Stockton-on-Tees. [*Wright, Gasholder, Stockton.* 12.]

1867. Wright, John Roper, Messrs. Wright Butler and Co., Elba Steel Works, Gower Road, near Swansea.

1859. Wright, Joseph, Metropolitan Railway-Carriage and Wagon Co., Saltley Works, Birmingham; and The Gresham Club, London, E.C.

1895. Wright, William, 16 Great George Street, Westminster, S.W.; and Dudley, 8 Louvaine Road, New Wandsworth, London, S.W.

1871. Wrightson, Thomas, Messrs. Head Wrightson and Co., Teesdale Iron Works, Stockton-on-Tees.

1891. Wroe, Joseph, 26 Park Avenue, Manchester, S.E.

1891. Wylde, Thomas, P. O. Box 1048, Johannesburg, Transvaal, South Africa; and care of Messrs. F. A. Robinson and Co., 54 Old Broad Street, London, E.C.

1886. Wylie, James, 218 Alfreton Road, Nottingham.

1895. Wylie, John Condie, Appantoo Gold Mining Co., Axim, Gold Coast Colony: (or Pendarves Road, Camborne.)

1865. Wyllie, Andrew, 1 Leicester Street, Southport.

1877. Wyvill, Frederic Christopher, 19 East Parade, Leeds.

1889. Yarrow, Alfred Fernandez, Isle of Dogs, Poplar, London, E.

1895. Yarwood, William James, Works Manager, River Weaver Navigation, Northwich.

1881. Yates, Louis Edmund Hasselts, District Locomotive and Carriage Superintendent, Eastern Bengal State Railway, Saidpore, Bengal, India: (or care of Rev. H. W. Yates, 98 Lansdowne Place, Brighton.)

1880. York, Francis Colin, Locomotive Superintendent, Buenos Aires and Pacific Railway, Junin, Buenos Aires, Argentine Republic: (or care of W. Hannay, 18 Portland Street, Leamington.)

1889. Young, David, 11 and 12 Southampton Buildings, London, W.C.

1879. Young, George Scholey, Engineer, Thames Iron Works, Orchard Yard, Blackwall, London, E.

1874. Young, James, Managing Engineer, Lambton Engine and Iron Works, Fence Houses.

1892. Young, Robert, Superintending Engineer, Penang Steam Tramways, Penang, Straits Settlements.

1887. Young, William Andrew, Messrs. Lobnitz and Co., Renfrew, near Paisley [*Lobnitz, Renfrew.* 57, *Paisley.*]; and Millburn House, Renfrew, near Paisley.

1831. Younger, Robert, Messrs. R. and W. Hawthorn Leslie and Co., St. Peter's Works, Newcastle-on-Tyne.

ASSOCIATE MEMBERS.

1895. Ahrons, Ernest Leopold, Managing Engineer of Technical School, École Khédiviale d'Arts et Métiers, Cairo, Egypt.

1894. Almond, Michael, District Locomotive Inspector, Cape Government Railways, Queenstown, South Africa: (or care of Robert Almond, 21 Hawthorn Road, South Gosforth, Newcastle-on-Tyne.)

1894. Ambler, Frank, Assistant Resident Engineer, Alagoas Railway, Maceio, Brazil.

1894. Anderson, Tom Scott, 59 Wilkinson Street, Sheffield.

1895. Armstrong, George Edwin, Municipal Technical School, York Place, Brighton.

1894. Armstrong, William Henry, Water Works, Wellington Square, Calcutta, India.

1894. Aveline, William Rebotier, Messrs. George Gahagan and Co., Bellasis Road, Byculla, Bombay, India.

1888. Barker, Eric Gordon, Locomotive Superintendent, Wirral Railway, Dock Station, Birkenhead; and Guyse House, Oxton, R.O., near Birkenhead.

1893. Barker, Frederic William, 33A Hammersmith Broadway, London, W. [*Barker, Broadway, Hammersmith.*]; and 28 Prebend Gardens, Chiswick, London, W.

1895. Barnes, James, 75 Dickenson Road, Rusholme, Manchester.

1894. Baron, Francis Edward, Hampton Wick Iron Works, Kingston-on-Thames. [*Baron, Hampton Wick.*]

1893. Beazley, Ernest, care of Messrs. Antonio Giorgi and Co., Funchal, Madeira.

1895. Bennis, Alfred William, Messrs. E. Bennis and Co., Lancashire Stoker Works, Deansgate Foundry, Bolton.

1893. Bishop, Henry, 38 Gresham Street, Lincoln.

1895. Blaxter, Augustus Pearce, Jun., Messrs. Barnett and Foster, Niagara Works, Eagle Wharf Road, New North Road, London, N.

1895. Boulden, Frederick, The Technical School, St. George's Square, Sheffield.

1892. Bromly, Alfred Hammond, Choukpazat Gold Mine, Nankan Post Office, viâ Wuntho, Upper Burma: (or care of Thomas Hammond, Stanwell Street, Colchester.)

1895. Bruce, Robert Arthur, Messrs. Hick, Hargreaves and Co., Soho Iron Works, Crook Street, Bolton.

1893. Burden, Alfred George, Messrs. Tangyes, P. O. Box 818, Johannesburg, Transvaal, South Africa: (or care of George N. Burden, Oakfield, Teignmouth.)

1895. Burn, George Francis, Leeds School of Science and Technology, Cookridge Street, Leeds.

1890. Burne, Edward Lancaster, Messrs. Dickinson and Burne, Church Acre Iron Works, Guildford.

1895. Carver, Charles Frederick, Alfred Street Machine Works, Nottingham. [*Carver, Nottingham.*]

1895. Challenger, Godfrey Richard, Messrs. John Jameson and Son, Bow Street Distillery, Dublin.

1894. Clark, James Lester, Messrs. Clark and Aiton, 102 Fenchurch Street, London, E.C. [*Channeled, London.*]

1895. Clatworthy, Walter Angove, Acme and Immisch Electric Works, Ferdinand Street, Chalk Farm, London, N.W.

1894. Collis, Alfred Edward, Lincoln Science School, Monk's Road, Lincoln.

1895. Corby, Matthew, Messrs. Thomas Firth and Sons, Norfolk Works, Sheffield; and 160 Hagley Road, Birmingham.

1893. Corkhill, William, General Superintendent, Asiatic Steam Navigation Co., Calcutta, India.

1894. Coventry, Theodore, Messrs. Smith and Coventry, Gresley Iron Works, Ordsal Lane, Salford, Manchester. [*Gresley, Manchester.* 564.]

1893. Cowell, John Ray, P.O. Box 2141, Johannesburg, Transvaal, South Africa.

1895. Cowie, William, Lidgerwood Manufacturing Co., Soerabaya, Java.

1887. Crosland, Delevante William, 22 Royal Crescent, Kensington, London, W.

1895. Cust, Leopold, Gas Traction Co., 22 Chancery Lane, London, E.C.; and 99 Onslow Square, London, S.W.

1894. Dadina, Hormuz Minocher, Consulting Engineer, Khetwady, Bombay, India.

1894. Davey, Edward Ernest George, 15 Westmoreland Street, Marylebone, London, W.

1890. Davidson, Albert, 139 Norfolk Street, Sheffield.

1890. Day, Arthur Godfrey, Director of Studies, Science Art and Technical Schools, Bath.

1894. Dickinson, Harold, Central Electric Lighting Station, Yorkshire House to House Electricity Co., Whitehall Road, Leeds. [*Electricity, Leeds.* 1013.]

1891. Douglass, Alfred Edwards, South Staffordshire Water Works, Paradise Street, Birmingham.

1895. Dronsfield, James, Messrs. Dronsfield Brothers, Atlas Works, Oldham.

1895. Dubrule, Louis Henri Jean Baptiste, Messrs. Dujardin and Co., Lille, France.

1895. Dumas, Robert, Messrs. Siemens Brothers and Co., Woolwich.

1895. Duncan, William, Locomotive Department, Cape Government Railways, Uitenhage, Cape Colony.

1895. Dunn, Matthew, Manager, Gas Works, Selby.

1894. Dunolly, Alan, Albion Works, Hyde, near Manchester.

1894. Eastmead, Frederic James, 39 Victoria Street, Westminster, S.W.

1892. Edgcome, James Edmund, Resident Engineer, Electric Light Station, Kingston-on-Thames.

1893. Edmondson, Alfred Richard, Central Board School, Deansgate, Manchester.

1891. Edwards, Herbert Francis, Messrs. Forster Brown and Rees, Guildhall Chambers, Cardiff.

1894. Ewen, John Taylor, 14 Tremadoc Road, Clapham, London, S.W.

1895. Fawcett, Percy William, Tempered Spring Works, Rockingham Street, Sheffield.

1894. Fendick, Walter, Gas Works, Hemel Hempstead.

1894. Finlayson, David, Burnhead, Larbert, Stirlingshire.

1894. Fitz-Gerald, John Frederick Gerald, care of El Señor Ingeniero, Departamento de Vias y Obras F.C.S., Buenos Aires, Argentine Republic.

1895. Fleischer, Paul, Messrs. A. Guinness, Son and Co., St. James' Gate Brewery, Dublin.

1892. Fletcher, Joseph Ernst, Messrs. Charles Cammell and Co., Cyclops Works, Sheffield.

1895. Forbes, George Chichester, York Engineering Works, York.

1895. Foster, Edward Hornby, Messrs. John Foster and Son, Black Dike Spinning Mills, Queensbury, near Bradford.

1894. Graham, Maurice, Olive House, Central Hill, Upper Norwood, London, S.E.

1895. Greene, William Spencer Clayton, 33 Norfolk Street, Strand, London, W.C.; and 47 Edwardes Square, London, W.

1893. Gritton, Joseph, P. O. Box 1798, Johannesburg, Transvaal, South Africa: (or 97 Highbury Quadrant, London, N.)

1895. Groundwater, Samuel, Messrs. S. C. Farnham and Co., Old Dock, Shanghai, China.

1895. Groves, Montague, Moore's Rhodesia Concession, Salisbury, Mashonaland, South Africa.

1894. Hadengue, Charles Benjamin, Messrs. Carew and Co., Rosa Sugar Works, Rosa, North Western Provinces, India.
1895. Haines, Charles James, Southampton Water Works, Otterbourne, near Winchester.
1894. Hall, Robert Frederick, Cycle Components Manufacturing Co., Sampson Road North, Sparkbrook, Birmingham. [*Decimal, Sparkbrook*: 606.]
1894. Hardy, William, Woodview, Bessbrook, County Armagh, Ireland.
1894. Harris, Herbert Nelson, St. Michael's Foundry, Bridport.
1894. Hawley, Cecil Edward, The Haven, Weybridge.
1894. Henderson, Arthur James, 2 Lombard Court, Gracechurch Street, London, E.C.
1895. Hockley, Norman Julius, Engineer, Corporation Electricity Works, Burton-on-Trent.
1895. Horner, Joseph Gregory, 17 Vernon Terrace, Twerton-on-Avon, Bath.
1895. House, Henry A., Jun., Manager, Liquid Fuel Engineering Co., Columbine Ship Yard, East Cowes, Isle of Wight.
1893. Human, Edwin, Superintendent, Technical School, Colombo, Ceylon; and Halifax House, Robinson Street, Cinnamon Gardens, Colombo, Ceylon.]
1894. Hyde, George Herbert, Managing Engineer, Colombo Commercial Co., Colombo, Ceylon.

1895. Ingham, William, Burrator Reservoir Works, Sheepstor, Horrabridge, R.S.O., South Devon.

1893. Jenkin, Charles James, Rose Lea, Deganwy Street, Llandudno.

1895. Kennedy, Robert Baird, Fish Dock Road, Grimsby.
1893. Kershaw, Thomas, Technical School, Huddersfield.
1894. Kerslake, Walter Edmund, 34 Great George Street, Liverpool.
1893. Kirk, Percy Roebuck, 2 Forest View, Epping New Road, Buckhurst Hill, S.O., Essex.

1895. Larard, Charles Edward, Battersea Polytechnic Institute, Battersea, London, S.W.
1893. Lea, Arthur Henry, Messrs. Lea and Warren, Kettering.
1895. Longbottom, John Gordon, 11 Grassington Terrace, Keighley.

1894. Mansfield, Edwin Albert, 1 Aldermanbury Buildings, London, E.C.
1893. Manton, Arthur Woodroffe, New Docks 14 and 15, H. M. Dockyard, Portsmouth.

1895. Massey, Leonard Fletcher, Messrs. B. and S. Massey, Openshaw, Manchester. [*Masseys, Openshaw.* 300.]

1894. McGeorge, James, Bombay Burmah Trading Corporation, Rangoon, British Burmah, India.

1895. Messer, Edgar Harrisson, P.O. Box 1910, Johannesburg, Transvaal, South Africa: (or care of John Messer, Danbury, Alexandra Road, Reading.)

1894. Mills, Arthur Edwin, Colmar, Clifton Wood Road, Bristol.

1893. Mitchell, James Frederick Bruce, Messrs. J. F. B. Mitchell and Co., Mazagon Iron Works, Bombay, India.

1894. Monckton, Charles John, Superintendent Engineer, Messrs. T. H. Saunders and Co., Darenth Paper Mill, near Dartford.

1895. Moore, Thomas Lamb, Messrs. James Moore and Sons, Millfield Foundry, Belfast. [*Moore, Millfield, Belfast.* 466.]

1893. Mountain, Benjamin, 82 Ravenswood Terrace, Hyde Park, Leeds.

1895. Mount-Haes, Andrew, 7 Grove Road, Surbiton.

1893. Moylan, William Morgan, care of Messrs. Grindlay and Co., Calcutta, India.

1894. Murphy, Edward Owen, R.N.R., Chief Engineer, R.M.S. "Empress of Japan," Vancouver, British Columbia.

1889. Nasmith, Joseph, 61 Barton Arcade, Manchester.

1895. Nesbit, David Mein, Messrs. Ashwell and Nesbit, 12 Great James Street, Bedford Row, London, W.C. [*Platerack, London.*]; and Victoria Foundry, Leicester.

1894. North, Horace, St. George's Engineering Works, Trafalgar Street, Brighton.

1893. Paterson, Robert Mair, Gorhambury, Willesden Lane, London, N.W.

1895. Penn, William Cooper, 15 Victoria Street, Westminster, S.W. [*Penniform, London.* 3075.]

1893. Pertwee, Herbert Arthur, Messrs. Elliott's Metal Co., Pembrey Copper Works, Burry Port, R.S.O., Carmarthenshire.

1895. Phillips, Exham, Crescent Iron Works, Salford, Manchester; and Rostellan, Worsley, Manchester.

1894. Poppleton, Clement Francis, Messrs. Aveling and Porter, Rochester; and 8 Clifden Road, Clapton, London, N.E.

1895. Powell, Benjamin Newton, Manager, Lidgerwood Manufacturing Co., Soerabaya, Java.

1887. Price-Williams, John Morgan, 28 Ormiston Road, Westcombe Park, Blackheath, London, S.E.

1895. Pugh, Charles Vernon, Managing Director, Rudge-Whitworth Cycle Co., 71 Colmore Row, Birmingham.

1895. Pullar, Albert Evans, Pullar's Dye Works, Perth.

1894. Raleigh, Charles, P.O. Box 1905, Johannesburg, Transvaal, South Africa.

1893. Richey, William Frederick Albert, Messrs. Chance Brothers and Co., Lighthouse Works, near Birmingham.

1895. Ridley, Clarence Oliver, Sir W. G. Armstrong, Mitchell and Co., 8 Great George Street, Westminster, S.W.

1893. Roberts, Charles Thomas, 19 and 23 Chorlton Chambers, Johannesburg, Transvaal, South Africa. [*Roberts, Engineer, Johannesburg.*]

1895. Ross, Ernest Sydney, Inspection of Machinery Department, Macquarie Street, Hobart, Tasmania.

1894. Rossiter, James Thomas, Tynwald, Grove Park Road, Chiswick, London, W.

1894. Rowe, Daniel, Engineer, Ferreira Gold Mining Co., Johannesburg, Transvaal, South Africa: (or care of Mrs. Rowe, Trevingey Terrace, Redruth.)

1895. Russell, Frederick, Manager, Gas Works, Bexhill-on-Sea.

1894. Salis, Henry Rodolph de, Fairacres, Oxford.

1893. Schloesser, Robert, P. O. Box 209, Johannesburg, Transvaal, South Africa: (or care of Adolf Schloesser, 185 Sutherland Avenue, London, W.)

1893. Segundo, Edward Carstensen de, 28 Victoria Street, Westminster, S.W.

1891. Smith, Joseph Philip Grace, Polytechnic School of Engineering, 309 Regent Street, London, W.

1894. Smith, William Arthur, Midland Arches, Northampton; and 18 Albion Place, Northampton. [*Machinery, Northampton.*]

1891. Snell, John Francis Cleverton, Resident Engineer, King's Road Electric Light and Refuse Destructor Station, St. Pancras Vestry, London, N.W.

1893. Stockton, Joseph Sadler, Clovelly, Metchley Lane, Harborne, near Birmingham.

1894. Stone, Sidney, Great Eastern Railway, Stratford Works, London, E.

1894. Sutton, Hugh Reginald, Messrs. Mackies, Berks Iron Works, Caversham Road, Reading. [*Mackies, Reading.* 86.]

1887. Tabor, Edward Henry, Blackwall Tunnel Works, East Greenwich, London, S.E.

1893. Takatsuji, Narazo, Superintending Engineer, Calico Weaving Mill, Osaka, Japan.

1895. Takimura, Takeo, General Manager, Osaka Cotton Mill, Osaka, Japan.

1893. Talbot, Frederick William, Engineer and Manager, Water Works, Frimley Green, Farnborough, Hants.

1894. Taylor, William, Messrs. Taylor, Taylor, and Hobson, Slate Street Works, Leicester. [*Lenses, Leicester.* 134.]

1893. Tenney, Dennis, 53 Trinity Street, Hull.

1893. Thomasson, Lucas, Collands, London Colney, St. Albans.

1894. Thomson, Henry, Engineer, Cawnpore Woollen Mills, Cawnpore, India.

1893. Thomson, James Watson, Robert Gordon's College, Aberdeen.

1894. Thorpe, Walter Charles, Messrs. Goddard, Massey and Warner, Traffic Street, Nottingham.

1895. Threlfall, George, 50 Fenchurch Street, London, E.C. [*Gasify, London.*]

1893. Tomes, William Jameson, Locomotive Department, London and South Western Railway, Nine Elms, London, S.W.

1893. Tomlinson, William Augustus, P.O. Box 1978, Johannesburg, Transvaal, South Africa: (or care of John Tomlinson, Birthorpe Manor, Billingborough, near Folkingham.)

1893. Turner, Henry Arthur, care of Arthur Koppel, 96 Leadenhall Street, London, E.C.

1893. Walker, Charles Christopher, Messrs. Walker, Eaton and Co., Wicker Iron Works, Sheffield. [*Founder, Sheffield.* 376.]

1895. Wasdell, Abel, Superintendent, Water Works, Allahabad, India.

1894. Wasdell, Thomas, Jun., Water Works Road, Edgbaston, Birmingham.

1893. Watson, George, 39 Victoria Street, Westminster, S.W. [*Meterage, London.*]

1893. Wells, Sidney Herbert, Principal, Battersea Polytechnic Institute, Battersea, London, S.W.

1895. West, Charles Herbert, 5 Castle Street, Liverpool. [*Referee, Liverpool.* 5223.]

1895. Wild, Adamson George, care of W. S. Laycock, Victoria Street Works, Sheffield.

1893. Wilkins, George Cornelius, Sir W. G. Armstrong Mitchell and Co., Elswick Ordnance Works, Newcastle-on-Tyne.

1895. Williams, Henry Watson, 2 Beaufort Road, Clifton, Bristol.

1889. Willis, Edward Turnley, Hockley Hall and Whateley Colliery, Tamworth.

1890. Winmill, Hallett, P.O. Box 1161, Johannesburg, Transvaal, South Africa: (or care of C. C. Winmill, 114 Main Road, Bexley Heath, S.O., Kent.)

1895. Wort, Walter Edward, Liquid Fuel Engineering Co., Columbine Ship Yard, East Cowes, Isle of Wight.

1889. Wright, Howard Theophilus, Great George Street Chambers, Westminster, S.W. [*Heaterite, London.* 3248.]

1894. Young, Smelter Joseph, Messrs. E. Bennis and Co., Lancashire Stoker Works, Deansgate Foundry, Bolton.

ASSOCIATES.

1880. Allen, William Edgar, Imperial Steel Works, Cross George Street, Sheffield.

1881. Barcroft, Henry, Bessbrook Spinning Works, County Armagh, Ireland; and The Glen, Newry, Ireland.

1889. Barr, John, The Glenfield Engineering Works, Kilmarnock.

1886. Bennison, William Clyburn, Messrs. Samuel Osborn and Co., Clyde Steel and Iron Works, Sheffield; and 38 Wellington Street, Higher Broughton, Manchester.

1890. Birch, John Grant, 10 and 11 Queen Street Place, London, E.C.

1892. Bowman, Frederic Hungerford, D.Sc., F.R.S.E., Mayfield, Knutsford.

1888. Brown, Harold, Messrs. Linklater, Hackwood, Addison and Brown, 2 Bond Court, Walbrook, London, E.C.

1890. Burt, John Mowlem, Messrs. John Mowlem and Co., 19 Grosvenor Road, Pimlico, London, S.W.

1891. Carter, Frederick Heathcote, 9 Oxford Street, Manchester. [*Girder, Manchester.*]

1889. Castle, Frederick George, The People's Palace Technical Schools, Mile End Road, London, E.

1889. Chamberlain, John George, Messrs. Joseph Wright and Co., Neptune Forge, Tipton.

1888. Chrimes, Charles Edward, Messrs. Guest and Chrimes, Brass Works, Rotherham.

1890. Chubb, Richard, Messrs. Gillison and Chadwick, 10 Tower Buildings, Liverpool.

1893. Clarke, Edward Fuhrmann, Curzon Chambers, Paradise Street, Birmingham; and Four Oaks, Sutton Coldfield, near Birmingham.

1879. Clowes, Edward Arnott, Messrs. William Clowes and Sons, Duke Street, Stamford Street, London, S.E. [*Clowes, London.* 4558.]

1895. Cole, James Conrad, Messrs. Perkin and Cole, 29 Great George Street, Westminster, S.W.

1892. Cooper, Thomas Lancelot Reed, 27 Bothwell Street, Glasgow.

1894. Cowles, Lieut.-Commander William S., U.S.N., 123 Victoria Street, Westminster, S.W.

1892. Cryer, Arthur, University College, Cardiff.

1893. Darlington, John, Engine and Boiler Insurance Co., Manchester; and 3 Marlborough Gardens, Ealing, London, W.

1892. Davis, George Brown, Palace Wharf, Stangate, London, S.E.; and Cambridge House, 212 South Lambeth Road, London, S.W.

1895. Docker, Frank Dudley, Messrs. Docker Brothers, Birmingham Varnish Works, Icknield Port Road, Birmingham. [*Japan, Birmingham.* 3522.]

1892. Fauvel, Charles James, Fauvel Gold Recovery Co., Broad Street House, London, E.C.

1891. Foster, George, Hecla Foundry Steel Works, Sheffield; and Lyme Villa, Rotherham.

1889. Golby, Frederick William, 36 Chancery Lane, London, W.C.

1889. Götz, Carl Johann Wilhelm, Messrs. John M. Sumner and Co., 2 Brazennose Street, Manchester.

1889. Gregory, George Francis, Boarzell, Hawkhurst.

1894. Hayes, John, Messrs. W. P. Thompson and Co., 11 Burlington Chambers, New Street, Birmingham.

1887. Hind, Enoch, Edgar Rise, Nottingham.

1891. Jackman, Joseph, Persberg Steel Works, Pothouse Road, Attercliffe, Sheffield. [*Persberg, Sheffield.* 94.]

1884. Jackson, Edward, Midland Railway-Carriage and Wagon Works, Birmingham. [*Wagon, Birmingham.*]

1882. Jackson, William, Kingston Cotton Mill, Hull. [*Cotton, Hull.*]

1881. Lowood, John Grayson, Gannister Works, Attercliffe Road, Sheffield. [*Lowood, Sheffield.* 131.]

1895. MacBrayne, Laurence, 119 Hope Street, Glasgow.

1886. Mackenzie, Keith Ronald, Gillotts, Henley-on-Thames.

1868. Matthews, Thomas Bright, Messrs. Turton Brothers and Matthews, Phœnix Steel Works, Sheffield. [*Matthews, Sheffield.*]

1890. McGillivray, William, Messrs. Austin McGillivray and Co., Falcon Works, Sheffield. [*Austin, Sheffield.*]

1889. McKinnel, William, 234A Nithsdale Road, Pollokshields, Glasgow.

1891. McMeekin, Adam, Cogry Flax Spinning Mills, Doagh R.S.O., Co. Antrim, Ireland.

1890. Meggitt, Samuel Newton, Messrs. Ibbotson Brothers and Co., Globe Steel Works, Sheffield.
1892. Morley, John, Sanitary Engineering Works, Palace Wharf, Stangate, London, S.E.

1887. Neville, Edward Hermann, 35 Calle de Alcala, Madrid, Spain.

1874. Paget, Berkeley, Low Moor Iron Office, 2 Laurence Pountney Hill, Cannon Street, London, E.C. [*Gryphon, London.*]
1886. Peacock, William J. P., Wells Street, Oxford Street, London, W.; and 41 St. James' Street, London, S.W.
1888. Peake, Robert Cecil, Cumberland House, Redbourn, near St. Albans.
1887. Peech, Henry, Phœnix Bessemer Steel Works, near Sheffield; and 49 Victoria Street, Westminster, S.W.
1887. Peech, William Henry, Phœnix Bessemer Steel Works, near Sheffield; and Fernbank, Roehampton Park, London, S.W.
1894. Peters, Lindsley Byron, Messrs. G. D. Peters and Co., Moorgate Works, Moorfields, London, E.C. [*Peters, London.*]
1884. Phillips, Richard Morgan, 21 to 24 State Street, New York, United States. [*Sarita, New York.*]
1891. Pirrie, John Barbour, Barn Flax Spinning Mills, Carrickfergus, Co. Antrim, Ireland.
1891. Plant, George, Moseley Road School, Birmingham.

1891. Rankin, Thomas Thomson, Principal, Coatbridge Technical School and West of Scotland Mining College, Coatbridge.
1892. Reed, Ernest Charles, Riverside Mills, Dartford.
1891. Rowcliffe, William Charles, 1 Bedford Row, London, W.C.
1888. Rowell, John Henry, New Brewery, High Street, Gateshead.

1890. Schofield, John William, Messrs. Gregory and Bramall, Soho Steel and File Works, Sheffield.
1887. Scott, Walter, Victoria Chambers, Grainger Street West, Newcastle-on-Tyne. [*Contractor, Newcastle-on-Tyne.*]
1893. Simpson, Edward Percy, Messrs. Simpson and Co., 101 Grosvenor Road, Pimlico, London, S.W.
1891. Spencer, Francis Henry, P.O. Box 1338, Johannesburg, Transvaal, South Africa.
1892. Stead, John Edward, 5 Zetland Road, Middlesbrough.

1890. Taylor, John, 99 and 101 Fonthill Road, Finsbury Park, London, N.; and Stockport.
1887. Tozer, Edward Sanderson, Phœnix Bessemer Steel Works, near Sheffield.

1893. Wadham, Arthur, 171 Queen Victoria Street, London, E.C. [*Wadham, London.*]

1878. Watson, Joseph, Patent Office, 25 Southampton Buildings, London, W.C.

1892. Whitehead, Richard David, Municipal Technical College, Green Hill, Derby.

1892. Widdows, Francis R., Secretary, Norwich Technical School, Norwich.

1883. Williamson, Robert S., Cannock and Rugeley Collieries, Hednesford, near Stafford.

1891. Wiseman, Edmund, Cheapside and John Street, Luton. [*Wiseman, Luton.*]

GRADUATES.

1892\. Adams, Sidney Rickman, Consolidated Gold Fields of South Africa, P.O. Box 67, Johannesburg, Transvaal, South Africa: (or care of Henry Adams, 3 Colville Square, Bayswater, London, W.)

1885\. Addis, Frederick Henry, District Locomotive Superintendent, Rajputana-Malwa Railway, Sirsa, Punjaub, India: (or care of Messrs. Grindlay and Co., 55 Parliament Street, London, S.W.)

1895\. Alcock, Alfred Edwin, Yorkshire Engine Works, Sheffield.

1893\. Alderson, Charles Albert Heselton, Messrs. Ruston Proctor and Co., Sheaf Iron Works, Lincoln; and 13 Cheviot Street, Lincoln.

1890\. Alderson, George Alexander, Norland House, Ramleh, Alexandria, Egypt.

1894\. Ambrose, Sewell Powis, 383 Monument Road, Birmingham; and Swaffham Prior, Cambridgeshire.

1882\. Anderson, William, Locomotive Department, North Eastern Railway, Gateshead.

1889\. Ashford, John, Municipal Technical School, Midland Institute, Paradise Street, Birmingham.

1890\. Aubin, Percy Adrian, 29 St. James' Street, St. Helier's, Jersey.

1894\. Aylesbury, Thomas Antram, The Elms, Carshalton Road, Sutton, Surrey.

1888\. Bailey, Wilfred Daniel, Club de Residentes Estrangeros, Calle Victoria, Buenos Aires, Argentine Republic.

1894\. Barber, Edward Whitley, 6 Victoria Station Approach, Manchester.

1889\. Barrow, Arthur Robert Maclean, care of Messrs. William Watson and Co., 28 Apollo Street, Bombay, India: (or care of Mrs. Barrow, Holly Grove, Fittleworth, Pulborough.)

1893\. Bedbrook, James Albert Harvey, Haresfield, Blenkarne Road, Wandsworth Common, London, S.W.

1888\. Bell, Alexander Dirom, care of W. S. Bell, East Fortoun, Drem, Haddingtonshire.

1884\. Bell, Robert Arthur, Assistant Locomotive and Carriage Superintendent, South Indian Railway, Cuddalore (New Town), Madras, India: (or care of Mrs. R. C. Bell, 30 Brompton Crescent, London, S.W.)

1890\. Bell, William Thomas, Sunny Mount, Yarborough Road, Lincoln.

1895\. Blair, George, 16 Albert Road (East), Crosshill, Glasgow.

1888\. Bradley, Arthur Ashworth, Princess Estate and Gold Mining Co., Roodepoort, near Johannesburg, Transvaal, South Africa: (or care of Rev. Gilbert Bradley, St. Edmund's Vicarage, Dudley, Worcestershire.)

1887. Bremner, Bruce Laing, 21 Langworthy Road, Manchester: (or Streatham House, Canaan Lane, Edinburgh.)

1894. Britten, Thomas, Great Billing, Northampton.

1890. Brousson, Robert Percy, Westinghouse Electric Manufacturing Co., East Pittsburg, Pennsylvania, United States.

1880. Buckle, William Harry Ray, 11 Billiter Buildings, 49 Leadenhall Street, London, E.C.

1892. Bulwer, Ernest Henry Earle, Messrs. George Fletcher and Co., Poplar Iron Works, King Street, Poplar, London, E.

1891. Butcher, Walter Edward, 100 Lewisham Road, Lewisham, London, S.E.

1891. Buttenshaw, George Eskholme, Messrs. Guest and Chrimes, Brass Works, Rotherham.

1889. Calastremé, John Carlos, care of Robert Weatherburn, 93 Highgate Road, London, N.W.

1891. Caswell, Charles Henry, Naval Construction and Armaments Works, Barrow-in-Furness.

1894. Cater, John McIlvaine, Southdown, The Downs, Wimbledon.

1889. Challen, Walter Bernard, Messrs. Taylor and Challen, Derwent Foundry, 60 and 62 Constitution Hill, Birmingham.

1890. Chatwood, Arthur Brunel, Chatwood's Safe and Lock Co., 76 Newgate Street, London, E.C. [*Chatwood, London.* 6835.]

1891. Church, Harry, Ingeniero, para la Colonia San Gustavo, La Paz, Entre Rios, South America: (or care of George Church, Willington, Bedford.)

1895. Clarke, Leigh Theophilus, Telegraph Superintendent's Office, Manchester Sheffield and Lincolnshire Railway, Godley, T.S.O., near Manchester.

1890. Cleeves, John Frederick, Messrs. E. A. Cleeves and Co., 3 Mileage Wharf, Westbourne Park Road, London, W.

1892. Cleverly, William Bartholomew, Messrs. John Brown and Co., Perseverance Works, 6 Bow Common Lane, London, E.

1885. Clift, Leslie Everitt, 1 Holborn Place, High Holborn, London, W.C.

1892. Collingridge, Harvey, Messrs. S. Pearson and Son, Blackwall Tunnel Works, East Greenwich, London, S.E.; and Ingleborough, The Ridgway, Enfield.

1895. Connell, William Percival, Calle Sanz 14, Minas de Rio Tinto, Huelva, Spain: (or care of W. G. Connell, 83 Cheapside, London, E.C.)

1889. Cook, George Norcliffe, Messrs. Thomas Firth and Sons, Norfolk Works, Sheffield.

1888. Cox, Herbert Henry, Hillside, Falmouth.
1891. Cutler, Samuel, Jun., Messrs. Samuel Cutler and Sons, Providence Iron Works, Millwall, London, E.

1894. Darwood, John William, Ahlone, Rangoon, Burma.
1884. Dixon, John, Eastwood Villa, Lytham, near Preston, Lancashire.
1893. Douglas, William Saunders, Consett Iron Works, Consett, R.S.O., County Durham; and 60 Durham Road, Blackhill, R.S.O., County Durham.
1895. Dresser, Charles, 9 Vant Terrace, Vant Road, Tooting Graveney, London, S.W.
1891. Duncan, Martin Gordon, Lexden, 63 Elmfield Road, Upper Tooting, London, S.W.

1895. Ferguson. Victor Bruce, Altidore Villa, Pittville, Cheltenham.
1893. Fox, Frederick Joseph, 49 Farquhar Road, Upper Norwood, London, S.E.
1894. Fry, Henry Walter, Locomotive Department, London Brighton and South Coast Railway, Brighton; and Leydenburgh, Port Hall Street, Brighton.
1895. Fryer, Tom Jefferson, Totley Brook, near Sheffield.

1895. Gale, Robert Henry, 38 Scarsdale Villas, Kensington, London, W.
1895. Gallé, William Alexandre, Locomotive Works, Manchester Sheffield and Lincolnshire Railway, Gorton, Manchester.
1890. Garrett, Frank, Jun., Messrs. Richard Garrett and Sons, Leiston Works, Leiston, R.S.O., Suffolk.
1895. Gill, Charles Edgar, 9 Balmoral Place, Halifax.
1895. Griffith, Charles Leopold Troyte, Messrs. Bramwell and Harris, 5 Great George Street, Westminster, S.W.
1895. Griffiths, Alfred, Messrs. Guest and Brookes, Phœnix Iron Works, Poland Street, Oldham Road, Manchester.

1895. Hall, William Brasier, Inglewood, Christ Church Road, Cheltenham.
1894. Halsey, Charles Turner, Womersley House, Dickenson Road, Hornsey, London, N.
1890. Hatton, Thomas Reginald, Grosvenor House, Gloucester Road, Ross, Herefordshire.
1889. Hayward, Robert Francis, Salt Lake and Ogden Gas and Electric Light Co., Salt Lake City, Utah, United States.

1877. Heaton, Arthur, Messrs. Heaton and Dugard, Metal and Wire Works, Shadwell Street, Birmingham. [*Heagard, Birmingham.*]

1874. Hedley, Thomas, Room 20, Sherlock Building, Portland, Oregon, United States.

1893. Heinrich, Herbert Rodolph, 17 Buckingham Palace Road, London, S.W.

1894. Hodges, Frank William, Messrs. Alexander Wilson and Co., Vauxhall Iron Works, Wandsworth Road, London, S.W.; and Tullgarn, 37 Cromwell Road, West Brighton, Brighton.

1891. Hodgson, William James, Messrs. Hodgson and Hodgson, Central Chemical Works, Nottingham.

1887. Hogg, William, Craigmore, Blackrock, Dublin.

1894. Hollingsworth, Edward Massey, Corporation Gas Works, Warrington Old Road, St. Helen's, Lancashire.

1889. Hosgood, Thomas Watkin, Sketty, near Swansea.

1891. Hosgood, Walter James, Locomotive Department, Barry Dock and Railways, Barry, near Cardiff.

1889. Hosken, Arthur Fayrer, Locomotive Department, Caledonian Railway, St. Rollox, Glasgow.

1889. Howard, Geoffrey, Britannia Iron Works, Bedford.

1883. Howard, Harry James, Messrs. Colman's Mustard Mills, Carrow Works, Norwich.

1891. Hughes, Edward Sinclair Bremner, Madgefield, Helensburgh.

1894. Ironside, William Allan, Messrs. Ironside, Gyles and Co., 1 Gresham Buildings, Guildhall, London, E.C.

1894. Jamieson, James Lindsay Auldjo-, Messrs. Hawthorn Leslie and Co., St. Peter's Works, Newcastle-on-Tyne.

1894. Johnson, Walter Wroe, Castleton Foundry and Engineering Works, Armley Road, Leeds.

1890. Jones, Arthur Dansey, Locomotive Department, Lancashire and Yorkshire Railway, Horwich, near Bolton.

1891. Jordan, Frederic William, 42 Wells Street, Mortimer Street, Cavendish Square, London, W.

1889. Joy, Basil Humbert, 17 Victoria Street, Westminster, S.W.; and Manor Road House, Beckenham.

1895. Keen, Harry A., Patent Nut and Bolt Co., London Works, near Birmingham

1883. Lander, Philip Vincent, Lyndhurst, Hampton Wick, R.O., Kingston-on-Thames: (or care of W. W. Lander, Imperial Ottoman Bank, 26 Throgmorton Street, London, E.C.)

1894. Larmuth, William Oliver, Messrs. Thomas Larmuth and Co., Todleben Iron Works, Unwin Street, Cross Lane, Salford, Manchester; and 48 Fitzwarren Street, Pendleton, Manchester.

1881. Lawson, James Ibbs, Resident Engineer, New Zealand Railways, Wanganui, New Zealand.

1886. Lewis, William Thomas, Jun., Engineer's Office, Bute Docks, Cardiff; and 89 Albany Road, Cardiff.

1894. Lloyd, Thomas Zachary, Messrs. Nettlefolds, Smethwick, Birmingham; and Areley Hall, Stourport.

1883. Mackenzie, Thomas Brown, Messrs. J. Copeland and Co., Pulteney Street Engine Works, Glasgow; and 342 Duke Street, Glasgow.

1893. Mackesy, Walter, 17 Campden House Road, Kensington, London, W.

1895. Maia, Honorio de Araujo, Rua Municipal 17, Rio de Janeiro, Brazil.

1894. Mansfield, Alfred, Messrs. P. Orr and Sons, Madras, India.

1894. Mansfield, Walter, Messrs. Edwin Mansfield and Sons, 140 Great Clowes Street, Broughton, Manchester. [*Gaslight, Manchester.*]

1868. Mappin, Frank, Messrs. Thomas Turton and Sons, Sheaf Works, Sheffield.

1892. Marks, Alfred Pally, 155 Adelaide Road, London, N.W.

1895. Marriner, John, 12 Hyde Vale, Greenwich, London, S.E.

1889. Marshall, Frank Theodore, Messrs. R. and W. Hawthorn Leslie and Co., St. Peter's Works, Newcastle-on-Tyne.

1888. Marten, Hubert Bindon, Contractor's Office, Manchester, Sheffield and Lincolnshire Railway, Leicester; and Pedmore, Stourbridge.

1886. Mattos, Alvaro Gomes de, 98 Rua da Saude, Rio de Janeiro, Brazil: (or care of Messrs. Fry Miers and Co., Suffolk House, 5 Laurence Pountney Hill, London, E.C.)

1892. Miles, Frederick Hudson, Hampden House, Phœnix Street, St. Pancras, London, N.W.

1891. Mills, Matthew William, Moss Foundry, Heywood, near Manchester.

1867. Mitchell, John, Heathercliffe Lodge, Penistone.

1891. Mogg, Henry Hodges, Newbridge Hill, near Bath.

1894. Moon, Edgar Rupert, 9 Gloucester Terrace, Swindon.

1892. Murray, David James, 62 Lloyd Street, Greenheys, Manchester.

1878. Newall, John Walker, Newall-Cuningham Sheep Shearing Machine Co., 73 Cheapside, London, E.C.

1883. O'Connor, John Frederick, Messrs. O'Connor and Rutherford, 31 and 33 Broadway, New York, United States.

1883. Osborn, William Fawcett, Messrs. Samuel Osborn and Co., Clyde Steel and Iron Works, Sheffield.

1892. Osmond, Frederick John, The Tower, Bagot Street, Birmingham. [*Osmond, Birmingham.* 550.]

1881. Oswell, William St. John, Messrs. Oswell and Henry, Calle Defensa 117 al 119, Buenos Aires, Argentine Republic.

1883. Palchoudhuri, Bipradas, Moheshgunj Factory, Krishnugher, Bengal.

1895. Palmer, Henry Boswell, Jun., 219 New King's Road, Parson's Green, Fulham, London, S.W.

1887. Paterson, John Edward, Chief Mechanical Engineer's Office, New South Wales Government Railways, Wilson Street, Eveleigh, Sydney, New South Wales.

1895. Pearce, Herbert, Linotype Depôt, Castle Street, Endell Street, Long Acre, London, W.C.

1894. Petter, Percival Waddams, The Foundry, Yeovil.

1890. Philipson, John, Jun., Messrs. Atkinson and Philipson, 27 Pilgrim Street, Newcastle-on-Tyne. [*Carriage, Newcastle-on-Tyne.* 415.]

1884. Philipson, William, Messrs. Atkinson and Philipson, 27 Pilgrim Street, Newcastle-on-Tyne. [*Carriage, Newcastle-on-Tyne.* 415.]

1890. Powell, Frederick, York House, Malvern Link, Malvern.

1892. Power, Arthur Cyril, 17 Fordwych Road, Brondesbury, London, N.W.

1893. Price, William Frederick, Wyresdale, Wilbraham Road, Chorlton-cum-Hardy, Manchester.

1892. Ransom, Herbert Byrom, Messrs. Manlove Alliott and Co., 57 Gracechurch Street, London, E.C.

1895. Rayner, Harry Stafford, 68 Norroy Road, Putney, London, S.W.

1895. Read, George Henry, 7 Palmerston Road, Bowes Park, London, N.

1894. Readhead, Robert, Jun., Messrs. John Readhead and Sons, West Docks, South Shields.

1892. Redfern, Charles George, 4 South Street, Finsbury, London, E.C.

1884. Reynolds, Thomas Blair, 28 Victoria Street, Westminster, S.W.

1895. Riches, Carlton Tom Hurry, 8 Park Grove, Cardiff.

1894. Richmond, William Frederick, Great Brunswick Ironworks and Foundry Co., Sir John Rogerson's Quay, Dublin; and Shellness, Stradella Road, Herne Hill, London, S.E.

1892. Ridley, James Cartmell, Jun., 3 Summerhill Grove, Newcastle-on-Tyne.

1895. Roberts, Basil Owen, Cooper Steam Digger Co., King's Lynn.

1895. Robertson, T. Ernest, Benview, Dumbarton.
1889. Roope, Walter, Stisted, Badulla, Ceylon: (or care of Mrs. Roope, Hangerfield, Witley, Godalming.)
1884. Roux, Paul Louis, 54 Boulevard du Temple, Paris.
1888. Rümmele, Alfredo, 17 Via Principe Umberto, Milan, Italy.
1894. Russell, William Colin, Gwalia Tin-Plate Works, Briton Ferry; and Hafod, Swansea.

1890. Sanders, Percy Henry, Messrs. H. G. Sanders and Son, Victoria Works, Victoria Gardens, Notting Hill Gate, London, W.
1890. Saxelby, Herbert Raffaelle, 7 and 8 Ironmonger Lane, Cheapside, London, E.C.
1892. Scarfe, George Norman, care of George Scarfe, Gawler Place, Adelaide, South Australia.
1881. Scott, Ernest, Messrs. Ernest Scott and Mountain, Close Works, Newcastle-on-Tyne. [*Esco, Newcastle-on-Tyne.* 432.]
1892. Seymour, William Frederick Earl, Engineer's Office, Great Western Railway, Swindon.
1893. Sharpley, George Ruston, Messrs. Ruston Proctor and Co., Sheaf Iron Works, Lincoln.
1892. Shepherd, James Horace, Great Western Railway, Swindon.
1886. Silcock, Charles Whitbread, 12 Arlington Road, Surbiton.
1887. Simkins, Charles Wickens, Jun., Amguri Tea Estate, Amguri Post Office, Sibsagar, Assam, India: (or care of Charles W. Simkins, The Lodge, Lowdham, near Nottingham.)
1893. Simon, Ingo, 20 Mount Street, Manchester.
1894. Simpson, Lightly Stapleton, Trinity College, Cambridge; and 16 Kent Terrace, Regent's Park, London, N.W.
1894. Skinner, Russell Foster, 57 Lupus Street, Pimlico, London, S.W.; and 6 Cambridge Road, Brighton.
1895. Smith, Frederick Hardcastle, Steam Crane Works, Old Foundry, Rodley, near Leeds.
1895. Southward, Philip Edmond, Victory Printing Machine Works, Liverpool; and 11 Frederick Crescent, Brixton, London, S.W.
1892. Stokes, Frank Torrens, P.O. Box 1355, Johannesburg, Transvaal, South Africa.
1894. Suffield, Frank Wilson, Glen Lyn, Grove Avenue, Moseley, Birmingham.

1885. Tangye, John Henry, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham.
1884. Taylor, Joseph, 24 Hawthorn Grove, Heaton Moor, near Stockport.
1884. Taylor, Maurice, 39 Rue de Lisbonne, Paris.

1894. Thorpe, Wilfred Bertram, 20 Larkhall Rise, Clapham, London, S.W.
1895. Titren, Gerald Ernest de Keyser, Natal Government Railway Works, Durban, Natal.

1891. Vaizey, John Leonard, Locomotive Department, Great Eastern Railway, Norwich.
1892. Vezey, Albert Edward, Electrical Department, London and North Western Railway Works, Crewe.

1888. Waddington, Samuel Sugden, 35 King William Street, London Bridge, London, E.C.
1885. Wakefield, William Marsden, Messrs. John King and Co., 30 Strand Road, Calcutta, India.
1888. Waring, Henry, Engineer, Dublin Laundry Co., Milltown, near Dublin.
1892. Warton, Richard George Frank, Westerleigh, Llandaff, near Cardiff.
1895. Waugh, Hylton Norman Drake, Locomotive Department, London Brighton and South Coast Railway, Brighton.
1886. Wesley, Joseph A., Clarke's Crank and Forge Works, Lincoln.
1888. Whichello, Richard, Messrs. Max Nothmann and Co., Rio de Janeiro, Brazil: (or 44 Trumpington Street, Cambridge.)
1894. Whitelegg, Robert Harben, Locomotive Department, London Tilbury and Southend Railway, Plaistow, London, E.
1889. Wigham, John Cuthbert, Messrs. J. Edmundson and Co., Stafford Works, 35 Capel Street, Dublin.
1895. Wilkin, Ernest Vivian, Northumberland Engine Works, Wallsend-on-Tyne; and 11 Appold Street, Finsbury, London, E.C.
1892. Williams, Arthur Edward, Messrs. Nelson Brothers, Nelson's Wharf, Lambeth, London, S.E.
1895. Williams, Spencer, 9 Billiter Square, London, E.C.
1890. Wilson, Alexander Cowan, Manchester Sheffield and Lincolnshire Railway, The Newarke, Leicester; and Osgathorpe Hills, Sheffield.
1887. Wrench, John Henry Kirke, 173 West Huron Street, Chicago, United States: (or care of E. M. Wrench, Park Lodge, Baslow, Chesterfield.)
1890. Wright, William Carthew, General Post Office, Melbourne, Victoria: (or care of Dr. Gaskoin Wright, 253 Eccles New Road, Salford, Manchester.)

1895. Yeames, James Lamb, Messrs. Harland and Wolff, Belfast.
1891. Yerbury, Frederick Augustus, 17 Victoria Street, Westminster, S.W.

Institution of Mechanical Engineers.

PROCEEDINGS.

July 1895.

The Summer Meeting of the Institution was held in Glasgow, commencing on Tuesday, 30th July 1895, at Ten o'clock a.m.; Professor Alexander B. W. Kennedy, LL.D., F.R.S., President, in the chair.

The President, Council, and Members were received in the Institute of the Fine Arts, Sauchiehall Street, by the Honourable the Lord Provost, Sir James Bell, Bart., the Magistrates, and Town Council, and the Chairman and Members of the Executive Committee.

The Lord Provost said that on behalf of the municipality of Glasgow he desired to offer to the President, Council, and Members of the Institution of Mechanical Engineers a cordial welcome to the City. It was a source of gratification to the Municipality that Glasgow had been selected for the present year's summer meeting of the Institution, because, if there was one city in the kingdom that took an especial interest in the profession which the Institution represented, he thought it was Glasgow. It might be said with truth that theirs was not unselfish interest, because he believed that the prosperity of Glasgow was largely bound up with the progress, the prosperity, and the persevering exertions of the Members of the Institution. It was in connection with engineering, he could say without flattery, that Glasgow had attained her world-wide fame; and he felt it a double pleasure to welcome the Institution to a city which had nurtured the genius of Watt. On behalf of his colleagues he desired to express the hope that the Members would see much in Glasgow which would interest them, even if the City could not show them anything that they did not already know.

Sir RENNY WATSON, Chairman of the Executive Committee, said that on behalf of the Committee he had much pleasure in seconding all that had been said by the Chief Magistrate in welcoming the Institution to Glasgow. It was sixteen years since the City was last honoured by a visit from the Institution; and when the Members came to see what had been done here in the interval, he hoped they would judge the City leniently if they found it had not progressed as rapidly as some places in the south. He himself thought it had done fairly well, and that it need not fear inspection even by critical eyes. On behalf of the Executive Committee he could assure the Members that they had done what they thought was best and wisest to provide entertainment and possibly instruction in connection with the excursions announced in the programme. He hoped the meeting would be favoured with fine weather, on which Glasgow so much depended; and was glad to think that, after the heavy rain which had fallen at the end of last week, the Institution could now be welcomed to a purified and cleansed city. He trusted the Members would enjoy themselves during their visit; and he wished to join in offering to the Institution a cordial welcome to the City of Glasgow.

The PRESIDENT said that, on behalf of the Institution which he had the honour to represent, he desired to thank the Municipality of Glasgow and the Executive Committee for the kind way in which they had received the Members. Judging from his own feelings and from what he knew of the feelings of the Members, they were looking forward with much pleasure to their visit. Far from having any desire to assume the position of critics, they were convinced that they would go away a great deal wiser for what they saw than they were before. There was no place in the United Kingdom which could afford more pleasure and more instruction from their own point of view than Glasgow. It was pleasant to know that, in addition to the technical enlightenment they would obtain, they would also derive a great deal of personal enjoyment from the kindness of their friends and from the cordial way in which they had been received. On behalf of the Institution therefore he now tendered to the

Municipality their best thanks for the kind manner in which they had been received.

The Minutes of the previous Meeting were read, approved, and signed by the President.

The PRESIDENT announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and the following forty-four candidates were found to be duly elected:—

MEMBERS.

BENNINGTON, JOHN WILLIAM, R.N., .	Rochester.
BENNION, CHARLES, ...	Leicester.
CHARNOCK, JAMES, ...	Orehovo, Russia.
CORNISH, EDWIN, R.N., . . .	Chatham.
COUPER, SINCLAIR, ...	Glasgow.
DONKIN, HARRY JULYAN, . . .	London.
GAYNOR, Capt. HENRY FRANCIS, R.E., .	Chatham.
GRANT, THOMAS MAXWELL, . . .	Glasgow.
GRIFFITH, PERCY, ...	London.
HALSTEAD, JOHN HENRY, . . .	Taltal, Chili.
HOLGATE, CHARLES HENZELL, . .	Leeds.
HOMFRAY, SAMUEL GEORGE, . . .	London.
HORNER, JOHN, ...	Belfast.
KING, CHARLES PENROSE, . . .	Epsom.
LEA, WILLIAM ARTHUR, . . .	Preston, Ontario.
LUMSDEN, THOMAS TEMPLETON MACKIE, .	Edinburgh.
MACGARVEY, HOWARD, . . .	Dublin.
MCGEE, WALTER, ...	Paisley.
MORRIN, RICHARD, ...	Liverpool.
REW, JAMES HENRY, ...	Glasgow.
ROBINSON, WILLIAM, ...	Nottingham.
SHARP, JOHN HUTCHINSON, . . .	Glasgow.
VAN RAALTE, JOSEPH, . . .	Flushing.
WRIGHT, WILLIAM, ...	London.
YARWOOD, WILLIAM JAMES, . . .	Northwich.

ASSOCIATE MEMBERS.

AHRONS, ERNEST LEOPOLD, . . .	Cairo.
BRUCE, ROBERT ARTHUR, . . .	Bolton.
CHALLENGER, GODFREY RICHARD, . .	Dublin.
CLATWORTHY, WALTER ANGOVE, . .	London.
COWIE, WILLIAM, ...	Soerabaya.
FOSTER, EDWARD HORNBY, . . .	Bradford.
INGHAM, WILLIAM, ...	Horrabridge.
MASSEY, LEONARD FLETCHER. . .	Manchester.
ROSS, ERNEST SYDNEY, . . .	Hobart, Tasmania.
TAKIMURA, TAKEO, ...	Osaka, Japan.
WILD, ADAMSON GEORGE, . . .	Sheffield.

GRADUATES.

FERGUSON, VICTOR BRUCE, . . .	Burton-on-Trent.
GILL, CHARLES EDGAR, . . .	Sowerby Bridge.
PALMER, HENRY BOSWELL, JUN., . .	London.
RICHES, CARLTON TOM HURRY, . .	Cardiff.
ROBERTSON, T. ERNEST, . . .	Dumbarton.
SOUTHWARD, PHILIP EDMOND, . .	Liverpool.
TITREN, GERALD ERNEST DE KEYSER, .	Durban, Natal.
WAUGH, HYLTON NORMAN DRAKE, .	Brighton.

The following Papers were then read and discussed:—

"Hydraulic Stoking Machinery and Labour-Saving Appliances in modern Gas Works;" by Mr. ANDREW S. BIGGART, of Glasgow.

"Notes on Hydraulic Power Supply in Towns: Glasgow, Manchester, Buenos Aires, &c.;" by Mr. EDWARD B. ELLINGTON, of London.

At One o'clock the Meeting was adjourned to the following morning.

The Adjourned Meeting was held in the Institute of the Fine Arts, Sauchiehall Street, Glasgow, on Wednesday, 31st July 1895, at Ten o'clock a.m.; Professor Alexander B. W. Kennedy, LL.D., F.R.S., President, in the chair.

The Discussion upon Mr. Ellington's Paper on Hydraulic Power Supply was resumed and concluded.

The following Papers were then read and discussed:—

"Recent Engineering Improvements of the Clyde Navigation;" by Mr. James Deas, Engineer of the Clyde Navigation.

"Notes on modern Steel-Works Machinery;" by Mr. James Riley, of Glasgow.

The remaining Papers announced for reading and discussion were adjourned to a subsequent meeting.

The President proposed the following Votes of Thanks, which were passed with applause:—

To the Honourable the Lord Provost and Lady Bell, for their hospitable invitation of the Members to their Conversazione.

To the Executive Committee—particularly to Sir Renny Watson as Chairman, Mr. John Inglis as Vice-Chairman, and Professor Barr as Honorary Secretary, and to Sir William Arrol, M.P., and Mr. Stephen Alley as Chairmen of Sub-committees—for the admirable arrangements they have made for this Summer Meeting of the Institution in Glasgow; and for their kind invitation to the Excursion on the Firth of Clyde.

To the Proprietors of the numerous Engineering Works, Shipbuilding Yards, and other Establishments which have been opened to the inspection of the Members; and to the Glasgow Iron and Steel Co. for their hospitable entertainment of the party visiting their Works.

To the Directors of the Caledonian and North British Railways, for their kindness in affording special facilities for the Excursions over their lines.

The Meeting then terminated at One o'clock. The attendance was 298 Members and 129 Visitors.

HYDRAULIC STOKING MACHINERY AND LABOUR-SAVING APPLIANCES IN MODERN GAS WORKS.

By Mr. ANDREW S. BIGGART, of Glasgow.

The conditions of labour in almost all industries have undergone and are constantly undergoing continuous modification and improvement, due principally to the ever increasing uses to which mechanical appliances are being adapted. This statement may be aptly made of many of the modern Gas Works, for in no industry have the conditions of work been more radically altered. The bulk of the labour employed in gas works is absorbed in the retort house, in the handling of the coal previous to and after carbonization.

Hand Labour.—In works where hand labour is chiefly employed, according to the old methods which still retain sway in the great majority of instances, the following may be taken as representing the general routine of those having the most approved arrangements. The supply of coal is usually brought by rail to the position most convenient for the retort benches, where the wagons are emptied by hand. If necessary, as is generally the case, the lumps are broken into suitable size by hand. The retorts are next charged by hand labour; and after carbonization is completed, the coke is withdrawn also by hand. The coke is either wheeled out to the yard, or may fall below the floor to a lower level, to be there quenched by water. The surplus beyond what is required for firing the regenerative furnaces has then to be removed to the yard. In the yard hand labour is again called into requisition, to screen the coke, and fill it into the carts or wagons for distributing it to the consumers. The variations in the details of the handling are such that scarcely two works follow the same routine; the foregoing outline can therefore be taken only as generally representative.

Labour-Saving Appliances.—The same remark also applies to the following outline of the routine pursued in works where labour-saving appliances are largely used. The supply of coal in such modernised works is usually delivered direct from the railway truck into the coal breaker. After passing through this machine, and being all reduced to a proper size, it is raised by an elevator to a large hopper, so fixed that the coal can be automatically delivered into the hopper of any of the charging machines. The charging of the retorts is then done altogether mechanically by means of a hydraulic charging machine, by which it is done more evenly and otherwise better than by hand. After carbonization the coke is withdrawn again mechanically by a hydraulic drawing machine, entailing a minimum of labour to the attendant. The surplus coke, guided in its descent by shoots, falls into a bogie underneath the floor, and is run out to the yard. In some instances underneath the stage floor are placed conveyors, on which the coke is carried to circular revolving screens, whence it is delivered into large storage hoppers, or into the railway wagons, or into bags for small consumers.

The old methods involve continuous and repeated operations performed by hand; while the new are such that no hand labour is employed in dealing with the coal from the time it leaves the railway truck till it arrives there again in the form of coke. Thus hand labour is entirely superseded by mechanical power, to the great advantage of labourer and employer alike. The number of men required in the retort house under the new system is not half that required under the old method. The saving which this represents, after allowing for maintenance of plant and interest on additional capital, will average about one shilling per ton. As the quantity of coal which might be carbonized annually in this country under the improved system will amount to about 8,000,000 tons roughly, the saving to the gas consumers would be about £400,000 per annum if stoking machinery were fully adopted.

Stoking machinery is not of recent date, although successful plant for such work has been in use only a comparatively short time. For the successful working of the stoking machines, considerable auxiliary machinery is necessary.

Coal Breaker.—This machine, into which the coal is delivered direct from the trucks by shoot or otherwise, varies greatly in strength, according to the different classes of coal; but the principle of the machine is in nearly all cases the same. Fixed over the breaker is a hopper, which is kept filled with coal, thus keeping always a supply of coal directly in contact with the two top rolls, each of which has a series of claws shaped in cast steel and working into one another, thus drawing in and breaking the coal in its passage through the rolls. Here it is only partially broken, but it falls directly upon two other rolls, which break to suitable dimensions any remaining larger pieces. These lower rolls are set closer to each other than the upper pair, and their crushing teeth are much smaller and of a different form. The coal delivered from these lower rolls is raised by an elevator to the large storage hopper, from which the various charging machines draw their supplies. The breakers are necessarily of a strong design; the cheeks and gearing are of steel throughout, and in all other respects the machines are made equal to the exceptionally heavy work required of them. The elevators are of the usual kind, raising the coal in buckets fixed at short intervals on a travelling link-chain, which passes round two revolving wheels, one fixed at the top and the other at the bottom of the steel framing that carries the whole. In passing round the lower wheel the buckets dip into and bring up the coal to be raised; and in turning over the upper wheel they tip it into a shoot leading to the storage hopper.

Charging Machine.—Each charging machine, shown in Plates 57 to 59, has to serve a large number of retorts at varying heights, and also at varying distances from one another. Consequently the range, that is the extent of retort-bench surface requiring to be effectively served by the charging machine, is considerable. The horizontal range is obtained by laying rails parallel to the retort bench, along which the charging machine may travel. The vertical range is secured by raising and lowering the charging apparatus on the machine, by means of a hydraulic ram which is fixed to the machine itself. In addition therefore to the coal-regulating and

charging apparatus, the body of the charging machine has to be provided with gear for traversing and also for raising and lowering; while on the top of the framing at a sufficient height a large hopper is permanently fixed, capable of carrying from two to five tons of coal, or a still larger quantity if desired. The regulating gear, for delivering from the hopper in greater or less quantities the coal with which the retorts are to be charged, is fixed immediately underneath the hopper.

Method of Working.—The whole of the motions are automatic, and are regulated by a single lever L, Plates 58 and 60. The first step is to drop from the hopper, by means of the coal-regulating apparatus, a certain quantity of coal in front of a pusher plate, by which it is then pushed into the retort, and delivered by a series of six or seven pushes into successive equidistant positions, beginning from the far end and extending forwards through the whole length of the retort. These positions are so close to one another, and the form of the pusher plate is such, that the charge is left practically level throughout the retort. The apparatus for accomplishing this work consists of a horizontal slide-beam B, Figs. 2, 5, and 6, Plates 58 and 60, on which are placed two hydraulic rams, one for giving the forward movement to the pusher plate, and the other for drawing it back. Alongside the forward or pushing ram is a turning shaft carrying a series of stoppers SS, Fig. 2, which come into play in rotation as the shaft is revolved, and bring the pusher plate to a stand in the successive positions of its stroke, so as to spread the coal evenly over the whole length of the retort. When the drawing ram bringing the pusher plate back is near the end of its stroke, it is made to actuate the lever of a hydraulic valve V, Fig. 6, which in opening and closing puts in motion and also stops the coal feeding and regulating drum, Fig. 4. This coal-feeding gear consists of an open drum divided into segmental compartments, revolving underneath the coal hopper, and put in motion at regular intervals by means of a combined hydraulic ram and rack with wheel and ratchet gear, worked as already mentioned. The hand lever L, Figs. 2 and 5, regulating the pushing and drawing rams, serves also to lower the pusher into position when entering the retort, to raise it before returning, and

also to revolve the stopper shaft, Fig. 6, for spreading the charge in the retort. The usefulness of the charging machine is enhanced by the provision of various adjustments, such as means to vary the quantity of coal in a charge. This is effected by altering the length of stroke of the coal-regulating ram, Fig. 4, thereby giving a greater or less movement to the revolving coal-feeding drum. A larger or a smaller quantity of coal can also be placed at any particular part of a retort, if this should be desired owing to the temperature of the retort varying at different points.

This charging machine has now been in regular use for over two years, and is giving every satisfaction. Like all such work it has reached its present advanced state of efficiency only by a process of development. The first charging machine made of this kind was an experimental one; and while the main features have throughout varied little from the original design, the details have been considerably altered. In the experimental machine the coal hopper was attached to the charging apparatus, rendering it essential, when any change of height was required, to raise and lower the hopper and its contents. In all subsequent machines this position was discarded, with the exception of one machine specially so fitted, which is still doing good work. The alteration was found desirable, owing to the limit practically put on the coal capacity of the hopper, and also on account of the loss of time in raising and lowering the extra load. It was further found that the new plan gave a more compact design than the old. The coal-feeding drum was at first rotated by causing the back end of the pusher rod, when near the outer end of its stroke, to strike and carry with it a connecting-rod attached to a lever with pawl and ratchet combination on the drum shaft. Owing to the sudden blow however, this did not work satisfactorily. A single-acting hydraulic ram then took the place of the connecting-rod, with a spring opposite the ram to force it back; the ram was worked by a valve with lever, as at present. Although this alteration proved a great improvement, it was found desirable to replace the spring by a second hydraulic ram, as now adopted, Fig. 4, Plate 59; and this change was followed with the best results.

In the experimental machine, only fairly large pieces of coal were at first dealt with; and with these no trouble was experienced. As small coal however is extensively used in some gas works, a trial was made of it, with the result that, when once the coal began to run between the drum and the face-plate opposite, it sometimes did not cease running until the hopper was empty. As the opening could not be reduced without the risk of large coal jamming, and as each machine ought to be suitable for large and small coal alike, it was found essential to adopt some arrangement capable of dealing with all sizes. The difficulty was simply and effectually solved by fixing in the coal space in front of the drum a flap plate P, Figs. 2 and 4, Plates 58 and 59, having a lever and weight so attached as to cause it to press the coal against the face of the drum, and thus automatically to close, as a flap or clack-valve, the space through which the small coal formerly ran freely. The revolution of the drum moves back the flap without difficulty, and allows the coal to flow freely when charging.

Another point, for which it was not at first thought necessary to make any special provision, was the momentum of the coal-feeding drum when in motion. The amount of travel or rotation of the drum after the hydraulic ram had come to a stand was found to vary greatly. This was owing to the vanes in the drum being often in a different position in relation to the flap plate at the moment when the hydraulic ram ceased to exert its power. The evil effects were reduced to a minimum and rendered unimportant by simply fixing a continuously acting brake-wheel and brake on the end of the drum shaft.

A machine of this kind is naturally subject to a considerable amount of vibration and shock when in use, and especially is this so with the class of labour usually employed. For various reasons the former stokers are put to work these machines, which consequently have frequently to stand an amount of rough usage not usually associated with hydraulic machinery. Various minor matters revealed this usage. One was the effect on the copper tubes. More than the usual number gave way at the couplings, although the tubes themselves were of ample strength, the working pressure

being only 400 lbs. per square inch, while they were strong enough to stand a working pressure of 1,000 lbs. It was found desirable to alter the form of joint, and at the same time still further to increase the strength. The change consisted in simply putting in heavier copper tubes, and, instead of screwing the collars on at the ends of the tubes, in flanging the copper over, and soldering the collar behind the flange. Other minor details have also been improved, and modifications will no doubt continue to be made as the experience of actual working is gained.

About a year ago it was thought desirable, with a view to increasing the capacity of the coal hopper on the machine, to introduce mechanical power for traversing it along the floor; and a hydraulic motor, shown in Plates 64 and 65, was designed and made for this purpose. Hydraulic power, being already used in the machine, was naturally deemed the most suitable means to adopt, more especially as the load to be moved is a fairly constant one. It was decided to employ two hydraulic rams, with racks RR working in the opposite sides of a spur wheel, which is free to rotate forwards and backwards. On this wheel are secured two pawls JJ, each working in a spur wheel W alongside the first wheel; and as the first wheel moves in one direction, the pawl in gear on one of the side wheels goes with it; and on the motion of the first wheel being reversed, the second pawl takes the other side wheel in the opposite direction. Each of the side wheels revolves a separate mitre wheel; and as the two mitre wheels are geared into the opposite sides of a common mitre wheel M, the latter will revolve continuously in one direction. This common mitre wheel is keyed to a vertical shaft gearing in turn with the main axle A of the machine, through which it traverses the charger forwards or backwards as desired. To reverse the motion of the common mitre wheel, it is only necessary to reverse the action of the two pawls gearing into the side wheels. The hydraulic rams receive their water through a three-ported slide-valve V, Plate 64, which is made to reverse by a secondary key-valve K; the latter is controlled by a double lever D, which is actuated by the two hydraulic rams themselves as they approach the outer end of their

stroke. A simple arrangement of lever gear L has been adopted for reversing the pawls, so that by moving a hand lever the action of the hydraulic motor sends the charging machine in either direction at the will of the attendant. In order that the charging machine may be more completely under control while travelling, a brake B has been added to the motor, so that when the machine is nearing the stopping point the water is cut off and the brake brought into action.

Drawing Machine.—While the charging machine is employed in filling the retorts with coal, the drawing machine, shown in Plates 61 to 63, is for the reverse operation of withdrawing the charge from the retorts after it has been converted into coke. For this purpose a rod R is used, Plate 62, having on its outer end a plate P, free to swing or fixed, similar to that which pushes the coal into the retort in charging; but for withdrawing the coke the plate when free to swing can take either a vertical or a horizontal position. If free to swing it is tripped into a horizontal position while the rod is being inserted into the retort, above the coke, to the distance desired; and then as soon as the rod begins to be drawn forwards, its lower edge catches the coke and the plate tilts downwards, cutting into the coke with its vertical face, and bringing out in front of it part of the carbonized charge.

The action of the drawing machine is so similar to that of the charger, that there is considerable similarity in some of the parts. The arrangements for travelling the machine along in front of the retort bench, and for raising and lowering the slide-beam which carries the withdrawing rake, are in principle similar to the equivalent arrangements in the charger, although differing in detail. The drawing machine is so light in itself that it is unnecessary to apply mechanical power for traversing it backwards and forwards, as is done in the case of the charger. The drawer consists essentially of a carriage fitted with travelling gear, and having a vertical frame F fixed near the centre, Figs. 8 and 9, which carries the slide-beam with its pushing and drawing rams and connections for actuating the rake. This frame also carries on one side the hydraulic ram H

for raising and lowering the slide-beam as required. The rake is pushed into the retort and drawn out again by simply reversing a hand lever L, the motion of which not only reverses the valve, but also raises the point of the rake head at the beginning of its stroke, and lowers it at the end of the stroke. The rake is raised as it enters the retort, and passes over the coke; and is depressed again before beginning the return stroke, thus dipping into the coke and raking it out at every draw.

Results of Working.—The number of retorts charged or drawn per hour by these machines varies to a considerable extent in actual work. In some cases owing to special circumstances not more than 24 per hour are available for each machine; while in other more favourable instances as many as 48 per hour are allotted to each, and even with this larger number a reasonable time remains for rest for the stokers at the end of each hour. The labour of charging the retorts and withdrawing the coke is much lightened by these mechanical means, and the number of retorts charged and drawn for each stoker employed is largely increased. It might at first be imagined that coal placed in retorts in only six to eight large charges by the machine would not be so evenly laid as a much larger number of smaller charges put in by hand. The machine however lays the coal by far the most evenly, owing partly to the shape of the pusher head, which is bevelled so as to allow the small ridge of coal raised in pushing forwards to fall back when its support is removed on the withdrawal of the pusher head. Another advantage possessed by machine work over hand labour is that the charging is done more quickly, and thus there is a diminished loss of gas before the retorts are sealed up.

Apart from any other consideration, the mechanical charger could not fail to prove beneficial in view of the greatly improved conditions under which it enables work of a most trying nature to be carried on. The old method of hand charging was a severe ordeal for the stokers, requiring great exertion to get through the work in the shortest time possible, while exposed throughout to a high heat. Such adverse conditions are now entirely done away with where

mechanical stoking obtains. The single lever by which the whole of the operations are controlled is worked from such a position that the attendant is quite removed from the discomfort of close proximity to a high heat, while at the same time the former severe bodily exertion is replaced by light and easy work. Even greater improvements in the conditions of labour arise from the introduction of the drawer, which accomplishes, under all the better conditions attending the use of the charger, work of a still more trying nature. The withdrawing of the live coke from the retorts was work for which even the stokers themselves, accustomed as they were to it, admitted that mechanical appliances were required. Here again all is worked by a single lever, in such a position as to remove the attendant from the former discomforts of withdrawing the coke at a white heat at the mouth of the open retort.

The hydraulic power employed, at the pressure usually of about 400 lbs. per square inch, is distributed in the way generally adopted for similar installations. About two hundred of these machines are now in use or in course of manufacture. They have been adopted at many of the largest gas works in this country and abroad, including those of Glasgow (Plates 66 and 67), Birmingham (Plates 68 and 69) and Liverpool, the South Metropolitan and the Gas Light and Coke Companies in London (Plate 70), and the Vienna (Plate 71) and Amsterdam stations of the Imperial Continental Gas Association. Various typical methods of handling the coal and coke are shown in Plates 66 to 71, which will be readily understood without further explanation. In Glasgow, where the Corporation have adopted these machines for all their stations, the quantity of coal dealt with by them amounts to about 500,000 tons per annum.

Discussion.

Mr. WILLIAM FOULIS, General Manager of the Glasgow Corporation Gas Department, said there were in use in Glasgow a large number of these machines, which had given great satisfaction and were saving a great deal of money. Their peculiarity, as compared with hydraulic machinery generally, was that their reciprocating motions were more rapid and more quickly reversed than in other hydraulic machines. It might at first be naturally supposed that there would be some trouble from the shock consequent upon the quicker reversal of the water pressure; but this had been overcome by a proper arrangement of the valves. The machines had worked night and day for several years without giving the slightest trouble.

Mr. A. TANNETT WALKER, Member of Council, asked why so low a pressure had been adopted as only 400 lbs. per square inch for working the hydraulic machines. Did that pressure exist previously? or did the author after deliberate consideration adopt it? It appeared to him that a pressure of 400 lbs. would necessitate using a large bulk of water for dealing with the weights. For the new hydraulic power supply in Glasgow Mr. Ellington had now gone as high as 1,120 lbs. per square inch, instead of the 750 lbs. pressure previously adopted in London and elsewhere. He should also be glad to know what the flexible tubes conveying the water to the machines were made of, because for work of this kind he considered they were of the utmost importance.

Mr. EDWARD B. ELLINGTON asked for some information about the power that was needed to drive these gas-stoking machines.

The Honourable R. C. PARSONS said he certainly should have thought there would be considerable tremor from the reversal of the water in the two rams of the hydraulic motor, and also from the backlash of the racks and pinions. If this objection had been got

(The Hon. R. C. Parsons.)
over so satisfactorily as had been stated by Mr. Foulis (page 341), the details of the manner in which it had been done would be interesting.

Mr. James Platt, Member of Council, had listened to the paper with much interest, the subject of gas-stoking being a highly important one. He had had some experience in other kinds of machinery for easing the workmen engaged in these operations, by the application of mechanical power to help the men in charging and discharging the retorts. It should be borne in mind that the power required to withdraw the coke was not great: in ordinary practice this was done by one strong man; while two men were able to push in a charge about equal to that of the machine. This amount of power would at once determine the pressure of water to be employed For a higher pressure than 400 lbs. per square inch the hydraulic cylinder would be so small that it would not be convenient. This he imagined was the reason why so low a pressure had been adopted, and also because it caused less trouble with the flexible hose, of which a considerable length was required for enabling the machines to travel through the necessary distance in front of the retort benches. There was no doubt that mechanical stoking was much better than hand labour for charging gas retorts. Any one who had watched the men charging by shovel would have seen that it was impossible by that means to lay the coal so level in the retort as it was done by the machine. With the latter there was no difficulty in levelling up the successive charges, so as not to leave spaces in the bed of coal in the retort. It had been found that the adoption of mechanical means for helping the stokers had resulted in a great saving. The method of doing the charging entirely by machinery, as described in the paper, was he believed a more perfect one, and would result in a still larger saving; and he should imagine the machines would in time become general. It was true that there were also other means of charging retorts. Inclined retorts had been used in some works with great success; the coal was simply shot from a hopper into the upper end of the retort, and the coke was let out from the lower. There were some objections to

that plan, he believed; but on the whole it had worked exceedingly well, and had reduced the labour considerably.

Mr. JOHN WEST said that last year the Members of the Institution visiting Manchester had had the opportunity of inspecting the hydraulic machinery and also the compressed-air machinery employed in the gas works there. With a good deal of what had been said in the present paper he of course agreed, especially with the first part, which pointed out the great advantage to be derived from the adoption of machinery as compared with hand labour. The fact that a great saving was brought about had been fully demonstrated; and although no figures had been given showing the advantages in regard to cost, this information had been so fully furnished a week ago by Mr. Alexander Wilson, manager of the Dawsholm Gas Works, Glasgow, and President of the North British Association of Gas Managers, that perhaps it was not necessary for it to be repeated now. It would be found that there had been a great saving by the introduction of machinery over hand labour, amounting, as stated in the paper, to about a shilling per ton of coal coked. It had also been shown that the number of men in the retort house was less than half the number formerly employed. Evidence to this effect had been given before the royal commission on labour by Mr. George Livesey, who pointed out that fourteen men were now doing the work previously done by thirty-six, a reduction of 61 per cent.

It was stated in the paper (page 332) that stoking machinery was not of recent date, although successful plant for such work had been in use only a comparatively short time. An almost perfect machine however for drawing a charge and distributing the coal in a retort had been at work twenty years ago; and at the present time the machine perfected by himself for distributing coal was doing useful work in a large number of gas works in the South and other districts. The difference between the two machines he referred to was that in the later of them a certain amount of mechanical power was employed, while the earlier was worked by hand labour; and in gas works of moderate size the earlier was worked with some

(Mr. John West.)
economy, the saving sometimes amounting to more than one shilling per ton of coal carbonized. That machine was introduced in 1875, at which time he had also rendered the plan complete by introducing both coal-breaking and coal-elevating, which he believed had not been done before. In Manchester some years ago he had been informed that with the hydraulic stoking machinery working there the subsidiary work of breaking and conveying was still being done by men and ponies: the cannel was broken by hand, and the ponies drew it in wagons to the machine. The author was therefore to be congratulated on having now adopted mechanical means for effecting these operations. The machinery described in the paper was worked by hydraulic pressure acting upon rams; and he understood it had been found necessary to go on increasing the strength and power of the machinery. All who had introduced stoking machinery he believed had begun by making it too light; and practical experience had shown the necessity of continually increasing the size and strength of the parts. This was because the stoking machinery had to perform the most arduous work of any; it had to work night and day, Sundays and weekdays continuously; and any breakdown would be most serious. If any part of the machine broke down, the repair could not be delayed; it must be attended to at once and set right at any cost, otherwise the supply of gas would fail.

There was a great deal of difference in the work to be done in various parts of the United Kingdom. The machines described in the paper had first been introduced in Manchester, and had at first been made too weak, until it had gradually been found by experience that they must be made stronger. The difference between gas-stoking in Scotland and in England was great. In Scotland the cannel was easily pushed in and pulled out. In the south, owing to the difference in the quality of the coal, there was much greater difficulty; and he anticipated it would be necessary yet further to increase the strength of the machinery now described, before it would be strong enough for the work which it would have to do in the south of England. The average number of retorts charged and drawn per hour by each pair of machines he considered should be about sixty, counting the time from the commencement to the finish

of each bench of retorts; and though it had elsewhere been stated that sixty retorts could be charged in three-quarters of an hour, he had found that the work actually took an hour and three-quarters; the shorter time had been arrived at by taking no account of the intervals during which the machine was travelling from one retort to the next. No doubt the machines in Glasgow were giving great satisfaction, and he congratulated the Corporation on having adopted them. In Scotland the charges were small, and the material was burnt off in three hours, and it did not swell in the retort; whereas the Newcastle coal and the fine coal used further south in England did swell, sometimes so much as to render it difficult to get the drawing rake into the retort. Hence the necessity of increasing the power of the rams in the south of England, for forcing the rake in over the top of the charge in the retort. A report had been made a short time ago by the manager of the South Metropolitan Gas Works in London, where the hydraulic machinery described in the paper was working alongside his own compressed-air machinery; and it was mentioned that the cost for working twenty-five beds of retorts by a pair of the compressed-air machines was ninepence per ton of coal. Four pairs of these compressed-air machines had now been working there $2\frac{1}{2}$ years, night and day. During the last twelve months each pair of machines had been drawing and charging 250 retorts per day; whereas the hydraulic machines working alongside had been drawing and charging 160 retorts with somewhat smaller charges. The difference showed the need of adapting the stoking machinery to the special requirements of the work; and if he had now to put up compressed-air machinery in Scotland he should probably make it lighter than that employed at gas works in the south.

Mr. BRYAN DONKIN, Member of Council, thought the number of retorts charged and drawn per hour hardly gave a clear idea of what the machines would do; and he asked what was the weight of coal charged per hour, and the number of strokes made to and fro, especially in drawing the charges of coke.

Mr. Thomas Clarkson noticed that the operation of the machines had been simplified by using only a single hand-lever. It appeared from page 334 that one lever controlled no less than five operations:—the hand-lever regulating the pushing and drawing rams served also to lower the pusher into position when entering the retort, to raise it before returning, and also to revolve the stopper shaft. It was an advantage he thought to be able to control everything with one lever; but there was a good deal left unsaid regarding the details. Thus it was not clear whether a movement of the lever started a train of operations, which when once started could not be controlled by it; or whether each of the operations could be controlled independently at any time by a different movement of the lever; and he was sure mechanical engineers would like to know some further details as to how one lever could be made efficient in controlling five different operations.

Mr. Alfred Saxon asked for more information about the failure of the copper tubes, of which it was mentioned in page 336 that more than the usual number had given way at the couplings; he should be glad to know what was the usual number of failures in that class of work.

Mr. Jeremiah Head thought the great amount of ingenuity which had recently been expended in the charging and drawing of gas retorts was the direct consequence of the labour troubles experienced some two or three years ago; and it showed what was the general tendency of such troubles. Instead of making the manufacture of gas contribute a greater amount of remuneration to labour than before, which was the object of such disturbances from the workmen's side, the result generally was to reduce the amount of labour required, and thus to benefit the community at large. The latter he therefore considered were much indebted to Mr. Biggart, Mr. Foulis, and others, who had managed to make such complete and effective machinery as that described in the paper. Having recently been in the United States, he had seen there a great deal of machinery for charging coal into the furnaces of ordinary boilers.

On that side of the Atlantic much more attention than in England had been given to the firing of boilers by mechanical means. In one of the most complete arrangements that he had seen, where the coal was put into a large hopper and then fed mechanically into the boiler furnaces, the firing was able to be done by only one stoker to five boilers; whereas in the ordinary way, with hand-firing or other less complete means, the customary number was one man to two boilers.

He asked whether the author had turned his attention to the substitution of electrical for hydraulic power for working this kind of machinery. The operations appeared to him to resemble somewhat closely those of the ordinary travelling or overhead crane: there was the horizontal movement forwards and backwards, the longitudinal movement forwards and backwards, and the vertical movement. In America electricity was now gradually taking the place of all other powers for working the overhead cranes; and its development had been carried to such a high pitch of perfection as was scarcely known, or at all events scarcely seen, in this country. The great thing, as remarked by Mr. West, was to have power enough. It was common to begin with too little power, and failures were the result; but by use of motors with plenty of power to perform all the different operations, these were now accomplished remarkably well. In one place he had seen rolling-mill machinery—a nest of rolls and standards all complete—lifted bodily by an electrical crane, carried a great distance, and put down with remarkable quickness; the total weight lifted would be about 40 tons. At the Baldwin Locomotive Works in Philadelphia he had also seen an entire locomotive, weighing about 60 tons, carried a considerable distance and put down again by an electrical crane. There was one thing done in America which was not done in England: almost everything was worked there at double the speed. In England there seemed to be much fear of speed; but it was not so in America. In the use of electrical cranes the celerity with which all the movements were made was remarkable; it was necessary indeed to be wary in the shops, because the loads were moved about so quickly. Without pretending to any detailed knowledge of such machinery as

(Mr. Jeremiah Head.)
that described in the paper, it occurred to him simply to suggest whether the same kind of machinery employed for the same purpose could not be made even still more efficient and handy if electrical motors were substituted for the hydraulic motors. From what he had seen, it appeared to him certain that they could be made to work much more quickly, which meant greater efficiency in the long run.

Mr. Biggart said the question why so low a hydraulic pressure had been adopted as 400 lbs. per square inch had been answered by Mr. Platt (page 342), who had explained that the rams would have been inconveniently small, had the pressure been much increased. In some instances indeed it was found that with the 400 lbs. pressure rams of only $1\frac{1}{4}$ inch diameter gave ample power for all the work required.

The flexible pipe adopted (page 341) was of the kind common to many uses in mechanical engineering, namely ordinary armoured flexible hose. The body of the hose was made up of india-rubber and canvas, wound round with wire in the usual armoured form. The lowest pressure expected in testing the hose was 30 cwts. or 3,360 lbs. per square inch, even although the working pressure was only 400 lbs.

The power required to work the pusher bar (page 341), in what might be taken as a representative instance where there were twelve machines at work, had been found to be something between 15 and 20 I.H.P. in the usual run of the work. There was certainly still some shock (page 341), because the comparatively quick action of the valve in stopping the flow of the water to the hydraulic ram could not but have the effect of increasing the pressure largely at the moment of cut-off. But the shock due to the action of the valve had been reduced to such an extent that it did not now affect either the joints or the working of the machine. The valve employed was a hydraulic slide-valve with V shaped ports for rendering the cut-off as gradual as possible, with a consequent gentler increase of pressure. The most serious shock however was that which occurred whenever the rake rod was suddenly stopped against the stopper; this caused the whole machine to vibrate, and was due to

carelessness in working the machine. Machines in some respects like these had been supplied to Manchester fifteen to twenty years ago; but the present machines were so altered in principle and form as to render them essentially different in all important respects. Coal breakers and elevators (page 344) had been introduced in connection with these machines at Manchester about fifteen years ago; and the use of ponies was a thing of the past generation.

If almost perfect machines had been introduced twenty years ago (page 343), and had saved as much money then as now, it seemed surprising that so few of them had yet been introduced compared with the number that might have now been in use. In the hydraulic machines he had stated in the paper that considerable changes had been made; and he believed it was impossible that such machines could be introduced without undergoing certain modifications. Still further changes would most probably have to be made in the future as they had been in the past, as the result of further experience gained in actual work. At the South Metropolitan Gas Works at East Greenwich, where there were eight of the hydraulic machines in use, he had been informed by the engineer that the compressed-air machines could not do the work which these hydraulic machines were doing satisfactorily. Instead of the number of retorts stated by Mr. West (page 345) to be charged and drawn by these hydraulic machines per day, they usually worked 200 retorts per day; and they were stated by the engineer to be quite capable of doing regularly 250 retorts per day. It was quite true that the weight of the machines working with English coal should be increased as compared with those using Scotch coal. That the lightest of the hydraulic machines in Scotland were of ample strength to work with English coal had been practically demonstrated during the long coal strike in Scotland last summer, when the coal stores in the Glasgow gas works had run down to so low an ebb that large quantities were imported from England to keep the gas works going. The English coal, which swelled so much in the retorts, was brought to Scotland to the extent of thousands of tons, and was charged and drawn in the works by the same machines that charged and drew the Scotch cannel coal ordinarily used. According to

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the reports of the managers who had charge of the machines, they got on during those few weeks as well with the fine English coal as ordinarily with the Scotch.

The quantity of coal put into each retort (page 345) might be varied as desired. The usual charge was from $2\frac{1}{2}$ to $3\frac{1}{2}$ cwts. So far as the machines were concerned, there was no difficulty in dealing with any quantity up to $3\frac{1}{2}$ cwts. The time occupied in drawing varied, because where there was a heavy charge the coke was not so well burnt off, and also the space left for the rake head to pass in between the coal and the top of the retort was not so roomy; some practical difficulties of that kind usually compelled the machines to take a little longer time to do their work. The number of retorts drawn per hour varied according to circumstances from 24 to 48 per hour; in the paper he had given this as the average range of a great many results, because it was not desirable to take one particular place and confine all the observations to what was done there. Sometimes there were no more retorts available than 24 per hour to draw, while in other instances there were 48, and this higher number was done quite easily within the hour; in Glasgow 48 retorts were drawn in 45 minutes regularly. The usual number however was 40 per hour; and the time taken to do this number was always under 40 minutes. The charging machine sometimes did its work in six strokes and at other times in seven; the number varied with the length of the retort. The drawing also varied widely; sometimes it was done in a few strokes, and at other times it took as many as twelve or fifteen. If the heat was low and the coal not well carbonised, it was cemented with tar on the surface, and then the process of drawing was more difficult and tedious. The method mentioned by Mr. West (page 345) of calculating the time taken by these machines to do a given quantity of work was certainly new; he had never heard of it before in any such connection. In no case in England that he was aware of did the time taken to charge or draw a given number of retorts exceed on the average one minute per retort; and in nearly all instances it was considerably less than a minute.

As to all the operations being controlled by one lever (page 346), in the working of the coal drum, for instance, the lever first started the ram, and then the ram opened a valve and thus revolved the drum; and in coming back reversed the operation, and thus left the valve ready for the next stroke. These operations therefore, while controlled by the lever, were not done directly by it.

The statement that more than the usual number of the copper tubes gave way at the couplings (page 344) was of course indefinite. What might be the usual number in any particular works would depend greatly on how the apparatus had been treated; when proper care was exercised the breakages were few and far between. In many gas works he really did not know what the usual number of breakages would be; but in some cases it was considered that there were more copper tubes broken than there ought to be.

Some of the reasons why hydraulic or any other stoking machinery and labour-saving appliances generally had been introduced in gas works had been mentioned by Mr. Head (page 346). It was quite true that some of these appliances, such as the elevators, were not new (page 344). From the beginning of the present century at least there were in primitive country mills elevators doing good work on the same principle, and as effectually as any elevators in gas works at the present time. In the country mills, in Scotland at any rate, there were yet to be seen elevators which had been working for generations and were still working well. The principles were exactly the same, the only difference was in detail, the old principles being adapted to new kinds of work.

With reference to the application of electrical power (page 347), he had certainly thought on the subject; but the great objection that presented itself to such power was that it required the introduction of revolving machinery and shafting. In some of the gas-stoking machines now in use, other than those specially described in the paper, the shafts, gearing, belts &c., were almost endless; whereas in a retort house he had come to the conclusion that, of all kinds of machinery which should not be adopted, revolving machinery should be most avoided. In the hydraulic drawing and charging machines the principle had always been recognised of reducing the moving

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parts to a minimum; whereas with either compressed-air, electrical motors, or ropes, a large number of moving parts were essential, while the conditions were such that they never could be successful except at a serious cost for wear and tear.

Mr. Foulis said that with all new machinery difficulties were of course experienced; but in the Glasgow gas works he had some of the original machines which had been at work for three or four years, and they were now giving the greatest satisfaction. Still greater efficiency he had no doubt would be realised, with the progress of yet further improvements.

The President was sure the meeting would agree with him that their thanks should be given to Mr. Biggart for his paper, and for the diagrams by which it was illustrated. He had himself had the pleasure of seeing these machines of Mr. Foulis some years ago, in what he supposed must have been their early stage, and he had certainly been much struck with them; and from the description given in the paper of their latest form he had no doubt their working would now be still more interesting. Some of the questions of detail which had been asked and answered would be readily understood by those members who intended to take the opportunity of making for themselves an examination of the machines. Why machines of this kind should have to be so much more powerful than the men who previously charged and drew the retorts was perhaps at first a little puzzling. The real reason, he imagined, for the fact that more power was wanted in the machines, was that the actual direct operations of pushing in coal and pulling out coke were now carried out much more quickly by mechanical means than by hand. Although therefore the actual effort of the push or the pull might not be greater, the horse-power necessary was much greater, as the work was done in so much less time.

NOTES ON HYDRAULIC POWER SUPPLY IN TOWNS: GLASGOW, MANCHESTER, BUENOS AIRES, ETC.

By Mr. EDWARD B. ELLINGTON, of London.

The Distribution of Hydraulic Power in towns has not previously been brought directly before the Members of this Institution; and the fact that works of this character have just been completed in Glasgow renders the present meeting a suitable opportunity for dealing with an engineering subject of such continually increasing importance.

Existing Hydraulic Power Works.—The present position of the various undertakings which have been established for this purpose is summarized in the following Table 1 (page 354).

General Arrangement.—Of the hydraulic power works in London full particulars have already been given to the Institution of Civil Engineers (1887, vol. xciv, page 1; and 1893, vol. cxv, page 220); and as all such works have much in common, it is hardly necessary to add any detailed account of the most recent establishments in Glasgow and Manchester. The supplies in these towns differ from those given elsewhere in the higher pressure employed, namely 1,120 lbs. per square inch. This pressure was adopted in Manchester on the recommendation of the author and his colleague, Mr. Corbet Woodall, in order to render the power available under the most economical conditions for working the numerous hydraulic packing presses within the area of supply in that city. The works in Manchester have throughout been carried out under the supervision of Mr. Woodall, acting for the Corporation. In Glasgow also there is a considerable demand for power for pressing; and Mr. Gale, who is here responsible for the general scheme,

TABLE 1.—*Existing Hydraulic Power Works.*

Place.	Year of establishment.	Length of Mains.	Largest Diameter of Mains.	Engine Horse-Power.	Delivery of Water per week.	Number of Machines worked.	Pressure per sq. inch in Mains.
		Miles.	Inches.	I.H.P.	Gallons.	No.	Lbs.
Hull	1877	$2\frac{1}{2}$	6	250	100,000 to 500,000	58	700
London	1884	76	7	3,400	9,500,000	2,300	750
Liverpool	1888	18	6	800	1,000,000	153	800
Melbourne	1889	18	6	800	1,500,000	113	750
Birmingham	1891	$3\frac{1}{2}$	6	52	78,000	. .	700
Sydney	1891	12	6	688	710,000	200	750
Antwerp	1891	$4\frac{1}{2}$	12	1,000	3,300,000	Turbines at three stations	750
Manchester	1894	12	6	800	1,000,000	247	1,120
Glasgow	1895	9	7	600	nil	nil	1,120

considered it advisable to be able to supply the same higher pressure. The plans and specifications for these works were prepared by the author's firm as consulting engineers; and their execution has been under the control of the water department of the Corporation, and especially of Mr. Cochrane, Mr. Gale's assistant mechanical engineer. The general arrangement of the works in Glasgow and Manchester is shown in Plates 72 to 76, and 88. The engine house in each city is laid out to contain six sets of vertical triple-expansion engines of 200 I.H.P. each, of the kind introduced by the author in 1880; but in the earlier engines the cylinders were arranged compound with one high-pressure and two low-pressure cylinders. The scale on which the two stations have been planned is the result of the experience gained in London, which has demonstrated that for hydraulic power supply a station of about 1,200 H.P. is the most economical both in working expenses and in outlay of capital.

Engines.—The principal dimensions of the pumping engines in Glasgow are as follows, Plates 73 to 76:—high-pressure cylinder 15 inches diameter, intermediate 22 inches, low-pressure 36 inches, and all three 24 inches stroke; cranks set at 120°, in the sequence—high, low, intermediate; pumps single-acting, 13 inches diameter and 16 inches stroke; surface-condenser 530 square feet of condensing surface; crank-shaft journals 7 inches diameter; fly-wheel 7 feet diameter, weighing 2 tons. The engines are designed to work with a steam pressure of 150 lbs. per square inch above atmosphere, and this is the boiler pressure adopted in the recent stations in London and Glasgow; but in Manchester the pressure of only 120 lbs. is used, at the request of the committee of the Corporation who had charge of the undertaking. The Glasgow engines have not yet been tested for economy, but the London station of similar character at Wapping gave a consumption of 14·1 lbs. of water per I.H.P. per hour (Proceedings 1894, pages 536–51).

Boilers.—The boilers in Manchester are of the usual Lancashire pattern, five in number, 7 feet 6 inches diameter and 30 feet long. In Glasgow, as coke breeze is to be used for fuel, and as there is

ample space under the reserve water-tanks, it was determined to arrange the house for eight Lancashire boilers, 7 feet diameter and 30 feet long; at present only four have been fitted for the three sets of engines already in place. Since the station was designed, the Corporation have determined to add to the boilers Watmun automatic circulating apparatus for increasing their efficiency, Plate 75. Both in Manchester and in Glasgow two of Green's economisers, with 160 tubes each, have been fitted at the back of the boilers, Plates 75 and 88.

In the recent Wapping and City Road stations in London, Fairbairn-Beeley boilers have been used, as shown in Plate 89; and these with the economisers have given under trial the remarkable result of 11·11 lbs. of water evaporated from the temperature $63\frac{1}{2}^{\circ}$ of the hot-well feed and at the temperature of 362° corresponding with 143·3 lbs. pressure above atmosphere, or 13·44 lbs. of water evaporated from and at 212°, with one lb. of dry Nixon's coal, having a calorific value of 15·5 lbs.; the thermal efficiency of the boiler was therefore 86·7 per cent. It will be interesting to compare this result with that of the Glasgow boilers when they can be tried.

Accumulators.—The accumulators at the Manchester and Glasgow stations are of the same capacity, Plate 78, namely two at each station, having rams 18 inches diameter and 23 feet stroke, and each loaded with 127 tons inclusive of ram and casing.

Delivery.—Each set of engines is designed to deliver 230 gallons per minute at a speed of 60 revolutions or 240 feet of piston; but it is not intended that they should be run in regular work at more than 50 revolutions or 200 feet per minute. Assuming that five engines are working at the same time, the total regular working capacity of the stations when fully equipped is 57,500 gallons per hour at 1,120 lbs. per square inch. The maximum recorded during regular work in an hour at the Wapping station of the London Hydraulic Power Co. with five engines running has been 66,000 gallons at 800 lbs. per square inch, or an average for each of the five engines of 45 revolutions per minute. The reason for dividing the power at

a station into so many units is of course that the demand for power, as for lighting, is so irregular, as shown in Fig. 30, Plate 87, that the maximum demand is maintained approximately for only an hour or two during any day.

Site of Station.—The general arrangement of the Manchester and Glasgow stations has been determined mainly by the configuration and situation of the site selected. At first view the proposed site for the Glasgow works appeared difficult to lay out satisfactorily; but the solution ultimately arrived at, the author thinks, has fulfilled the required conditions in a fairly satisfactory manner, both mechanically and architecturally. The problem was solved by dividing the site into two areas at different levels by a heavy retaining wall, Figs. 6 and 7, Plate 77; and an attempt has been made to give the buildings a more imposing character than has been usual in such works. The position of the site seemed to require this, and the suggested elevation was at once accepted by the committee as being appropriate to its surroundings.

Water.—Both in Manchester and in Glasgow the water supply is taken from the corporation mains: so that no pumping is required to fill the tanks, and no filtering apparatus is needed. The whole arrangement of these stations is thereby much simplified as compared with those in London, where Thames or canal water is used; it is also unnecessary to have the same large reserve of water in the tanks. At the Wapping station in London, for instance, the tanks over the boilers have a total capacity of 237,000 gallons; and in addition there are underground reservoirs of filtered water, containing 500,000 gallons. In Manchester and in Glasgow the whole storage provided is only 230,000 gallons and 200,000 gallons respectively.

The pipes in the engine and boiler houses are all arranged on the duplicate or circuit system; and great attention has been given to the provision of sufficient access to all parts of the machinery.

Mains.—The supply from the stations in Manchester and Glasgow is taken to the streets through four mains, which are laid

in circuit, with valves at intervals of about 440 yards. Connecting mains have a valve at each end, so that the majority of buildings supplied have two ways by which the power can be obtained. The largest mains laid in Manchester are 6 inches internal diameter, and in Glasgow 7 inches, Fig. 17, Plate 82. The reason for the adoption of 7-inch mains in Glasgow is that there is a tendency to reduction of bore through corrosion due to the action of the Glasgow water; in consequence of which Mr. Gale wished the mains to be larger than the usual size. The mains at present laid or in progress of laying in Manchester and Glasgow are shown in Fig. 31, Plate 87, and Fig. 11, Plate 79; in Fig. 31 the four main circuits are distinguished by numbering. Sections of the valve-pits, stop-valves, and mains, are shown in Plates 80 to 82.

Joints.—The joints of the pipes are precisely the same as those used for the lower pressures in London and elsewhere, as shown full size in Fig. 18, Plate 82. The packings are gutta-percha rings inserted in a V groove, and the pipe ends are spigot and faucet. The setting back of the flanges, Fig. 17, so as to leave a considerable projection of the pipe ends beyond them, has greatly strengthened the pipes, without adding any weight; and so far as is known, only one failure of a pipe flange made on the author's plan has occurred during the last ten years. This failure occurred through a settlement in Bishopsgate Street, London. With pipes made without the flanges set back, many failures have occurred.

Registration of Supply.—Always supposing that the demand for the power is large enough, the commercial success of public hydraulic-power stations is largely dependent upon the proportion of the total output which can be accounted for by the meters employed. It is impossible to maintain a high efficiency of the machinery in use without a great deal of time and attention being given to the registration of the supply. The means employed for registration therefore, and for the maintenance of efficiency, are of great interest and importance in connection with the distribution of hydraulic power. This particular question has not been previously dealt with by the author so fully as to render it superfluous to revert to it here.

The London supply of power is so largely in excess of anything required elsewhere, that the experience gained in London is the most valuable; and the present remarks on this head will apply mainly to London.

Efficiency.—The first two matters to determine are the quantity of power delivered by the engines into the mains, and the rate of flow as far as possible throughout the day. The quantity of power is ascertained by a record of the engine revolutions, obtained with the usual counters. A constant is used, which for the London engines is reckoned as 4·8 gallons per revolution. This constant has been verified from time to time by observing the quantity delivered from the tanks during some hours by direct measurement; and no alteration is allowed in this constant under any circumstances. The counter readings are taken in London at six o'clock in the morning and six o'clock at night, and are entered in the engine-room log-book. These readings give the amounts from each station every twelve hours; and the returns from the several stations are collected and entered in a general log-book. Every six or seven weeks the meters are read on the consumers' premises, and the totals are collected; and the efficiency of the system is determined by the fraction representing the ratio of the quantity registered by the meters to the quantity pumped as determined by the counters. This ratio in London is found to vary considerably in different quarters of the year, and in different years. It has never been higher in any quarter than 0·9826, and has never been lower than 0·8560. The following are the ratios of efficiency for the ten years 1885 to 1894 in London, and for six years in Liverpool:—

	London.	Liverpool.
1885 ..	0·8665	
1886 ..	0·9250	
1887 ..	0·9400	
1888 ..	0·9370	
1889 ..	0·9545	.. 0·945
1890 ..	0·9576	.. 0·959
1891 ..	0·9089	.. 0·9853
1892 ..	0·9240	.. 0·9304
1893 ..	0·9119	.. 0·9543
1894 ..	0·9181	.. 0·9592
Average	0·9243	0·9555

The causes which produce the variations in these ratios of efficiency are themselves very variable; and with an extensive supply, such as obtains in London, it would be almost impossible to identify the locality of the losses, if the record of daily deliveries and the quarterly reading of meters were all there was to depend on. The sources of waste and error are of two kinds: firstly, those which occur before the supply reaches the consumers; and secondly, those which appertain to the consumers' machinery and to the meters. The losses of the first kind are made up of leakage past the suction-valves of the pumps; of leakage in the mains, and in the packings of the valve-glands connected with the mains; and of losses in frosty weather by pumping water to waste for the purpose of maintaining the circulation. The losses of the second kind are due to defects in the registration by the meters; to leakage from consumers' machines, where, as is generally the case, the exhaust water only is registered; and to drainage from consumers' machines and pipes. The last loss is considerable in winter, when consumers make a practice of draining their pipes after work every day.

Automatic Flow-Recorders.—In order to maintain a sufficient control over all these sources of waste, it is of the first importance to know the minimum flow through the mains at times when it may be supposed that no work is being done. To ascertain this, automatic recorders are fitted at all the pumping stations. One of these is shown in Plate 83; it consists of a drum, actuated by a clock, and carrying a paper strip, which is divided into quarters of an hour and hours by pins fixed on the drum; and over the drum are a series of armatures carrying pins, which prick a hole in the paper as each engine completes 100 revolutions. The descent of the armature is determined by electric contact, and one armature is electrically connected with each engine. The clocks at the different stations are synchronized, and the paper tapes are cut off daily, and the maximum and minimum deliveries during an hour are registered daily. The maximum delivery is chiefly used for determining load factors, and the amount of power required for supplying a given number of machines; while the minimum daily registration is of the greatest

value in determining the condition of the whole system, including the consumers' own machinery. The minimum flow varies greatly from day to day, but it never falls below a certain amount. This mode of registration was introduced by the author in 1888; and it has been found that the minimum flow rises pretty regularly as the supply is augmented. The following are the maximum and minimum registrations in London for the June quarters from 1888:—

Year.	Total Water pumped in June Quarter. Gallons.	Maximum Flow per hour. Gallons.	Minimum Flow per hour. Gallons.	Annual Load Factor.
1888	29,238,000	39,120	1,200	0·286
1889	39,873,000	49,920	1,776	0·328
1890	48,172,000	61,248	1,604	0·306
1891	65,386,000	79,330	3,360	0·339
1892	77,103,000	91,920	3,984	0·326
1893	82,586,000	101,760	4,500	0·323
1894	96,876,000	114,096	4,800	0·338

It will be observed that the minimum flow has increased at a greater rate than the maximum; and that the maximum has followed fairly closely the increase in output. The latter fact is more clearly brought out by the comparison also given for the same years of the load factor, that is, the ratio of the average flow per hour to the maximum flow.

The causes which have led to the comparatively large increase in the minimum flow since 1890 have been extremely difficult to ascertain. Since 1890 a great deal more hydraulic power has been used at the stations themselves, because most of the water from the river has since then been pumped into the unfiltered-water reservoirs by means of hydraulic pumps; but as the hydraulic power so employed is registered, this should not have affected the ratios of efficiency, which have been lower for the years 1891–94 than in 1887–90. Recently arrangements have been made to stop for one hour on Sunday morning all use of hydraulic power at the stations; and during the current year the minimum flow has fallen to 4,080 gallons in the hour, with a delivery of 112,000,000 gallons in a quarter, and a maximum flow of 144,000 gallons per hour; these figures show as good a result as in any previous year. From such facts as these, and for other reasons, it appears probable that the principal cause of the difference is to be found in the meters and in the consumers' machinery.

Detection of Waste.—The whole of the 76 miles of mains in London are as a rule in communication with one another; but certain valves are kept closed in such a way that the several main circuits are in communication with one another at the central station only. The superintendent at the central station has it then in his power at any time to divide the supply into four distinct sections; and by observation of the pressure gauges it can readily be ascertained through which section an abnormal flow is occurring. The main in which this abnormal flow is proceeding has then to be shut down at intervals, till at last the leak is run to earth. Great care and experience are required to determine the exact spot, as the water seldom appears through the surface of the street; and usually the only indication is the noise it makes in passing through a valve very slightly opened, which is detected through a metal rod pressed against the valve and held to the ear. Irrespective of any special indication afforded by the minimum readings, the whole of the mains are being constantly tested in this manner; but it is a work of considerable difficulty, because the supply has to be maintained as required throughout the night, and it is only during two or three hours in the early morning that anything of the kind can be done, and even then special arrangements have to be made with the consumers. The principal difficulty arises from the very small flows that have to be detected; for instance, the quantity of power water pumped into the mains and unregistered during the last quarter of 1894 was 6,900,000 gallons out of a total of 111,000,000 gallons, or 6·22 per cent.; but this 6,900,000 gallons to be accounted for by testing the mains is the result of water flowing continuously at the rate of say 3,000 gallons per hour, which is thus only about 2 per cent. of the maximum rate. The whole of this flow is distributed throughout 76 miles of mains, and over 2,200 machines with all their pipes and accessories. At the pressure of 750 lbs. per square inch 3,000 gallons per hour would pass through an orifice of only 5–16ths inch diameter: which shows how small in reality the leakage from the mains must be.

The principal source of waste is undoubtedly on the consumers' premises. It has been found necessary to inspect regularly all consumers' machinery, in order to prevent waste from leaky valves

and glands. Every machine from which the exhaust is measured is thus inspected every quarter, and the owners are called upon to make good defects. Many of the meters in use cannot be depended upon to register small flows, and a good deal of waste passing leaky valves thus fails to get registered ; but some of the waste occurring in this way does evidently get registered, because it is almost invariably found that the quantity unregistered is less than would be represented by the minimum flow. Thus in the figures just given for the last quarter of 1894 about 30 per cent. of the minimum flow was registered. A further cause of loss has already been mentioned, namely the drainage of pipes and cylinders on consumers' premises. This no doubt is the cause of the registrations being better in the summer quarters than in the winter. In severe frosts the drainage of the pipes and cylinders is an important matter, and it has been found advisable to facilitate the practice. There are other losses due to washing out and testing the mains &c. ; water used for testing extensions of mains is allowed for in the registered quantity. On the whole therefore it is no doubt a good result to have succeeded in registering an average of 93 per cent. of the quantity pumped during the nine years 1886–94.

Frost.—The severe and prolonged frost of last winter did not seriously affect the supply. About 1,150,000 gallons was pumped to waste during Sundays, in order to maintain the circulation ; but after allowing for this, 91·65 per cent. of the total water pumped was registered. This fact alone is conclusive ; but in a few places sub-mains in exposed positions were frozen, though in nearly every case they were quickly cleared. No consumer, it is believed, was seriously inconvenienced. The frost was down in the ground quite three feet in places, and there were five or six instances of broken mains. The damage done was greater than on any previous occasion. The surface of the roads was so hard that the water could not get through the paving, and in two or three places found its way into cellars. In two instances the water was forced between the concrete and the wood paving, floating the latter, and at last finding a vent about a hundred yards away from the break. It was not found necessary to relay the pavement thus lifted, except in a few places, for it settled

down all right again after the water had run off. There were other novel experiences of the severity of the weather. In the Thames Embankment subways there were several degrees of frost, and during its continuance, in order to reduce the risk, the area of supply was divided into sections, and the embankment main had thus a dead end; the temperature fell, the main contracted, a large number of the joints opened, and huge icicles formed round the flanges. As soon as this was discovered, the valve shutting off the City was opened, the water which is sent into the mains at 60° flowed through, and thawed the pipes that had contracted, and most of the joints again became quite sound.

In connection with this question of warming the water, it is interesting to note that the water pumped from the river was below freezing point. The water is heated by passing it through the surface condensers of the engines; but at the new stations where the triple-expansion engines are used, it was found that the temperature could not be raised much above 40° in the filtered-water tanks; and in order to maintain the water at the higher temperature of 60°, it was necessary to destroy the vacuum in the condenser, thereby rendering the engine less economical for the time being.

Another experience may be mentioned in connection with low temperatures, which shows that high apparent economy is not always real economy. At the Wapping and City Road stations the economisers are arranged much in the same way as shown in Fig. 8, Plate 77, for the Glasgow works. The temperature of the gases leaving the economisers was reduced to 238° or 240°, and the temperature of the hot-well condensed water entering the economiser was 65° or 70°. The consequence has been that it has been found necessary to renew the economiser tubes after three years' work, owing to the condensation on the outside of the tubes and their consequent corrosion. The cost of the renewal is larger than the saving of fuel effected. Arrangements are now being made to obtain a higher hot-well temperature.

Meters.—At first sight it would appear desirable to use high-pressure meters. Where these are used, the conditions of supply are

much simplified, because the condition and arrangements of the consumers' machinery are then of no direct consequence to the works supplying the power, since all water taken from the mains for any purpose is measured; and this is undoubtedly the ideal arrangement. There are however difficulties in the way. The high-pressure meters to stand 750 to 1,200 lbs. per square inch are necessarily costly. For hydraulic purposes it is essential in the author's opinion that they should be positive meters. A positive meter has three disadvantages: it will never continue for a long period to register a small flow; it offers considerable resistance to the flow at high velocities; and if it gets out of order, it may stop the flow almost entirely. Now a stoppage of supply from any cause is more serious than a temporary failure to register; and the balance of advantages is found to be ultimately in favour of the low-pressure meters registering the exhaust, from a tank into which the exhaust-pipe discharges. The kind of meter adopted by the author is the Parkinson, illustrated in Plate 84, which is closely similar to a gas meter. If it stops working, the tank overflows, and the nuisance causes a report to be sent in at once. It will register every drop of water, provided the water is clean and the meter properly set. On the other hand, it takes up a good deal of room; and if dirt or rubbish is allowed to pass into the drum, its accuracy is soon affected. A good deal of trouble is experienced from this cause. Where bad oil and packing are in use, or the glands and rams are in a bad condition, these meters have frequently to be changed two or three times in a single quarter; while in other places, where the machinery is better attended to, they will work for two years or more. With the Kent positive low-pressure meters, illustrated in Plate 85, which are largely used in London, there is not the same difficulty; and in many places these are preferred, because the space taken up is so small and there is no noise from the falling water. But they do not register accurately a small flow. On the whole they are well adapted for high pressure; and in several places it is only on the high-pressure side that the power can be registered: as for instance at the London Docks, where only a portion of the supply is taken from the hydraulic-power mains, the remainder being supplied from the dock pumping-stations. The principal difficulty with high-

pressure meters is in connection with the counter: the spindle must be light, in order to avoid loss of pressure; and the stuffing-box must be kept tight under the wear. After passing 1,000,000 gallons they have been found under test still accurate within 1 per cent.

Application of Power.—Hydraulic power has to be supplied under competition with steam, gas, and electricity; and the success which has attended its introduction shows conclusively that it is well able to meet this competition for lifting and for other intermittent work. None of the supply systems which have been established have aimed at meeting the demand for continuously running motors, except in Antwerp, where the supply has been laid out as a means for generating electricity for lighting. At first sight it is somewhat difficult to see how this can be an economical mode of employment. There are however a few places in London where the hydraulic power is used to generate electric current. The best method of conversion is undoubtedly an arrangement such as is shown in Plate 86. The apparatus consists of a Pelton wheel, with the armatures of the dynamo mounted on the same shaft. The following are the particulars of a trial made with this apparatus at the Hydraulic Engineering Works at Chester in October 1894:—Pelton wheel 18 inches diameter, fifty-four buckets; Elwell-Parker shunt-wound dynamo for charging accumulators, having a commercial efficiency of 87 per cent. as tested by the makers; speed 1,671 revolutions per minute; bore of nozzle 0·175 inch; hydraulic pressure 725 lbs. per square inch; output $37\frac{1}{4}$ ampères at 120 volts; water consumption 20 gallons per minute; power in water 10·15 horse-power, in output 5·99 horse-power; efficiency 59 per cent. This is not the highest efficiency that could be obtained, for the wheel and dynamo were not perfectly adapted to each other; external resistance had to be used for keeping down the voltage, and at this output the dynamo was somewhat overworked. In a previous trial, with 0·16 inch nozzle and an output of 26 ampères at 122 volts, the efficiency was 59·86 per cent. It is unlikely however that, even under more favourable conditions, the conversion can be effected with a greater efficiency than 66 per cent.

Comparison of Hydraulic and Electric Power Supply.—It is interesting therefore to enquire whether there are any grounds for the assumption that hydraulic power obtained otherwise than from a natural head of water can be used economically for generating an electric current. It so happens that the materials are available for a comparison between the cost of a public supply of hydraulic power and that of electricity obtained from a central station on almost exactly the same scale. The particulars given in the following Table 2 (page 368), and plotted as a diagram in Plate 90, are taken from the records of the London Hydraulic Power Company and of the Westminster Electric Supply Corporation for the year ending 31st December 1894. In making the comparison, 1,000 gallons of water at 750 lbs. per square inch is taken as equivalent to 6·518 Board of Trade units of electricity.

This analysis shows that the station cost of the hydraulic power is 5·172*d.* per thousand gallons pumped at the pressure of 750 lbs. per square inch; while the corresponding cost of an equivalent amount of electric energy reduced to the same hydraulic standard is 9·014*d.* per thousand gallons: or on the electrical standard of Board of Trade units, 0·793*d.* and 1·383*d.* respectively. The output during the year, the capital employed, and the average rate received for both supplies, are nearly the same. The coincidence of the figures is extraordinary, except in the cost items, in which their divergence is equally remarkable. No other conclusion can be drawn than that for some reason or other, not hitherto explained, hydraulic power is much less costly to produce than electricity. The Westminster electric supply is one of the largest in the country, and its cost is one of the lowest. The London hydraulic supply is the greatest anywhere, and is produced no doubt very cheaply. In neither however has the minimum cost been reached, for in both of them the station cost in the newer installations is considerably below the average for 1894. For instance the station cost of the hydraulic power supply from the Wapping Station for 1894 was only 4·177*d.*, as against 5·172*d.* for the whole supply; while the station cost of the Davies Street Station of the Westminster electric supply is equivalent to 8·731*d.* per thousand gallons, as against 9·014*d.* for the

TABLE 2.—*Comparison of Hydraulic Power Supply and Electric Supply, compiled from the reports of the London Hydraulic Power Supply* (L.H.P.) *and the Westminster Electric Supply* (W.E.S.) *for the year* 1894. *See Plate* 90.

1894.	Totals. L.H.P.	Totals. W.E.S.	At Gallons at 1,730 feet head. L.H.P.	At Gallons at 1,730 feet head. W.E.S.	At Board of Trade Electric Units. L.H.P.	At Board of Trade Electric Units. W.E.S.
	£	£	Gallons.	Gallons.	Electric Units.	Electric Units.
Capital outlay	471,552*	411,018				
Output			400,313,000	396,256,000	2,609,240	2,582,801
Quantity sold			332,390,000	333,430,000	2,166,520	2,173,298
Received for supply	49,237	50,729				
Average price obtained			Per 1,000 galls. 35·55 pence	Per 1,000 galls. 36·51 pence	Per unit. 5·45 pence	Per unit. 5·6 pence
Station Costs.	Totals.		At 1,000 Gallons at 1,730 feet head.		At Board of Trade Electric Unit.	
	£	£	Pence.	Pence.	Pence.	Pence.
Coal	3,276	5,842	1·964	3·539	0·301	0·543
Oil, Water, and Engine-room expenses	1,351†	1,228	0·810	0·743	0·124	0·114
Salaries and Wages	3,071	6,345	1·811	3·839	0·282	0·589
Repairs and Maintenance	929	1,478	0·557	0·893	0·086	0·137
Totals	8,627	14,893	5·172	9·014	0·793	1·383
Individual Station	Wapping § £	Davies St. ¶ £	Wapping § Pence.	Davies St. ¶ Pence.	Wapping § Pence.	Davies St. ¶ Pence.
Coal	1,242	3,263	1·684	3·906	0·258	0·600
Oil, Water, and Engine-room expenses	385	600	0·522	0·718	0·080	0·110
Salaries and Wages	1,072	2,500	1·453	2·993	0·223	0·459
Repairs and Maintenance	382	931	0·518	1·114	0·079	0·171
Totals	3,081	7,294	4·177	8·731	0·640	1·310

* Including £56,000 for new site and station, started October 1894.
† Including £400 for water rights and £129 for gas lighting.
§ Wapping Station only; output 177,000,000 gallons in 1894.
¶ Davies Street only; output 1,306,791 units in 1894.

wholesupply. It may be thought that the low annual load-factor of say 0·18 for the electrical supply, as against 0·33 for the hydraulic, accounts for most of the difference; but under the able control of Professor Kennedy the influence of a low load-factor has been to a great extent neutralized by running the machinery actually in use at nearly full load. Moreover the figures of other electric installations, such as the St. James' and Pall Mall, where the load-factor is much higher than in the Westminster district, show a similar difference of cost as compared with the hydraulic supply. Now it is obvious from the figures of the London and Westminster installations that, as the output during the year was the same, while there is so great a difference in the annual load-factor, the maximum horse-power employed is much greater for the electric than for the hydraulic supply; but the output per unit of capital outlay seems to be much the same. This is no doubt owing to the greater concentration of demand in the area supplied with electricity. If a large amount of power is concentrated in a single station, it is practicable to work that station much nearer to its maximum capacity than if the same power had to be supplied from two or three stations. In the London hydraulic supply, while the annual load-factor is 0·33, calculated on the maximum delivery at any time during the year, the load-factor of the whole plant in use during the year under the most favourable conditions is only 0·20, and is often much lower; in other words, more than one-third of the whole plant is always in reserve, and in some years as much as half. The proportion of plant out of use altogether or not running at full load at the periods of maximum demand is no doubt much less at most electric-lighting stations; and the load-factors of the two systems calculated upon the total station plant probably do not differ widely. The fact that the load-factor calculated on the maximum flow is lower for the electric supply than for the hydraulic does not, other things being equal, account for the larger part of the difference of cost. This is shown also by a comparison of the cost of the hydraulic supply during a week when the output is large and during another when it is small. During the week ending 18th October 1894 altogether 9,095,000 gallons were pumped at the London hydraulic power stations; and during the

week ending 27th December, 5,902,000 gallons only. The increased cost for fuel in the latter week was 0·317*d.* per 1,000 gallons, and for wages 0·77*d.* per 1,000 gallons, making 1·087*d.* per 1,000 gallons; whereas the average excess cost of the electric supply is more than $3\frac{1}{2}$ times as much, and in the item of coal nearly five times as much.

The immediate question however is the economy of using hydraulic power for generating electricity; and it will be seen from the foregoing figures that, with a loss of 33 per cent. of the hydraulic energy during conversion into electric energy, the station cost of 0·793*d.* per Board of Trade unit would rise to 1·189*d.*, or 0·194*d.* below the cost 1·383*d.* of the direct current of the Westminster supply. The cost will be further increased by the wages, superintendence, and repairs at the converting stations; so that on the whole there does not seem much probability of any economy resulting from this method of generating electricity on a large scale. It may be mentioned that the principal reason which led the late Professor Van Rysselberghe of Ghent to advise the combined method for the electric supply of Antwerp was that he considered the losses of distribution of the electric current would be much less on that method. The losses of distribution however are not very serious either way; and the direct or the combined method must ultimately stand or fall, the author considers, on the relative generating cost per unit. Mr. L. Moris has kindly furnished the particulars in Table 3 of the working of the Antwerp hydraulic service. The very low cost per thousand gallons pumped is evidently due to the small amount of wages paid at the central station; and the figures include nothing for superintendence, water supply, lighting of station, removal of ashes, or repairs to machinery. At least $1\frac{1}{2}$*d.* per thousand gallons should be added for these items, in order to make the cost comparable with that of the London stations. It will be noticed that the reduced output in April increased the cost only 0·46*d.* per thousand gallons, or say 15 per cent., while the output was only 58 per cent. of that in January. It seems however that, notwithstanding the low cost at which the hydraulic supply is obtained in Antwerp, the general results of the combined method during the

TABLE 3.—*Antwerp Hydraulic Power Service.*

1895.	January to April. Four months.	January. Maximum month.	April. Minimum month.
Quantity pumped . .	Gallons. 59,080,000	Gallons. 20,178,000	Gallons. 11,772,000
STATION COST per thousand gallons.	Pence.	Pence.	Pence.
Coal	2·618	2·483	2·614
Engine-room Stores .	0·118	0·130	0·134
Wages	0·693	0·512	0·840
Total . .	3·429	3·125	3·588

first nine months of working have not been satisfactory. It is stated that the arrangements have proved more costly than the usual direct method, not only in first cost but in working expenses. The capital outlay per electric unit would probably be greater; but there seems no sufficient reason why the working expenses should be increased. Further information is required before an explanation can be given. While the combined method does not seem to have any sufficient basis for a general system of distribution, it is evident from the foregoing figures that electricity can be economically generated by means of hydraulic power artificially obtained; and the latter can therefore be used with advantage as a supplement to ordinary methods of generating electrical energy.

Hydraulic power is clearly much the most economical in those applications where the direct pressure can be utilized, such as for lifting and pressing. Where rotary motion is needed, the special circumstances of each case will determine what power shall be used, and all are now more nearly on a par as regards cost. For motors running regularly for several hours a day the London Hydraulic Power stations now supply power at a rate of 1*s.* 6*d.* per 1,000 gallons, which is equivalent to 2·76*d.* per Board of Trade unit of

electricity, or say 3*d.* per brake horse-power per hour. It is questionable whether small powers can by any means be obtained at a lower rate, when all the items of cost are taken into account.

Hydraulic Power Supply for Drainage.—Hydraulic power mains have recently been put down in the streets of Buenos Aires for the purpose of drainage; and although the supply is not intended to be sold to the public, yet the conditions are such as to render interesting a general outline of the undertaking, as an instance of a hydraulic-power supply in towns. As acting partner of Messrs. Bateman, Parsons, and Bateman, the Engineers to the Argentine Government, the Hon. R. C. Parsons had a few years ago to face the problem of draining the two low-lying Boca and Barracas districts, which are indicated in the plan, Plate 91. In order to avoid the great cost and difficulty of laying deep sewers, he ultimately decided to lay out the works on the plan of numerous small automatic pumping stations, and finally adopted hydraulic power as the best means for working the pumps at the sumps. The general plan of the works is shown in Plate 92. There is a central station, containing two compound surface-condensing horizontal engines, having cylinders $15\frac{1}{2}$ and 27 inches diameter with 22 inches stroke, Plate 93; each engine works direct a double-acting pump of 5 inches diameter and 20 inches stroke, and is capable of delivering 175 gallons of water per minute at 58 revolutions. Space has been provided for a third engine, whenever the work to be done at the sumps renders it necessary. There are three Lancashire boilers, 6 feet diameter by 22 feet long, with a Green's economiser of 120 tubes. The roof of the boiler-house is a tank, which is kept supplied from the water-works mains. The water after use is run to waste into the sewers. The engines can be run with or without the condensers, as it is sometimes inconvenient to use the water in the tank for condensing purposes, owing to the high temperatures during the hot season. There are two accumulators, having rams 18 inches diameter and 20 feet stroke, which were loaded at the trials to 800 lbs. per square inch; but the machinery is calculated to work at 750 lbs. per square inch under ordinary conditions. The station is fitted out with the usual accessories.

The mains carried through the Boca and Barracas districts are nearly $8\frac{1}{2}$ miles in length, and their arrangement is shown in the plan, Plate 91. There is a duplicate supply to every sump. The largest mains are 5 inches bore, and the smallest 2 inches bore. There are in all seventeen sumps, one of which is shown in plan in Fig. 43, Plate 94. Each sump contains duplicate hydraulic sewage-pumps on the author's system, Plates 94 to 96. The quantity of sewage to be dealt with varies considerably at the different sumps; but it was found practicable to reduce the whole of the pumps to two sizes, and as a matter of convenience the only substantial difference between them was made in the stroke. They are all single-acting, and have plungers 30 inches diameter; twenty-two of them are made with 3 feet stroke, and twelve with 4 feet stroke; the maximum speed of working is ten double strokes per minute. The head of water and friction on the delivery sewers are also different at the different sumps, and the diameter of the hydraulic working rams was varied to suit. The pressure on the side rams, which perform the upstroke, is constant; the water from these rams is returned in the downstroke to the central hydraulic cylinder. The sewage runs into the sumps by gravity, and when they are nearly full a float starts one of the pumps; and when the level falls a certain amount, the float stops the pumps. If the level of sewage continues to rise after the first pump is at work, another float starts the second pump. The pumps therefore always work so as to cause a flushing velocity in the rising main or sewers. The exhaust power-water is discharged into the sewage-pump cylinders, thus serving to dilute the sewage and keep the plungers clean. The whole arrangement is automatic. At the time the machinery was completed, there were no houses connected to the sewers, so that the tests had to be made with water run into the sewers for the purpose; the results of the engine tests are given in Table 4 (page 374). The delivery sewers discharge at different points into the main outfall sewer, which is everywhere above the level of the Boca and Barracas drainage area.

The whole of the mains were tested to 1,500 lbs. per square inch after being laid. In laying them during the hot weather it was found necessary to protect them from the heat of the sun, in order to

TABLE 4.

Hydraulic Power Supply for Drainage in Buenos Aires.

Trials of Two Compound Horizontal Condensing Pumping Engines at central station.

21–22 November 1893.		Engine No. 1.	Engine No. 2.
Duration of trial	hours	10	10
Diameter of High-pressure cylinder	inches	$15\frac{1}{2}$	$15\frac{1}{2}$
„ „ Low „ „	inches	27	27
Stroke	inches	22	22
Revolutions, total during trial	revs.	35,150	35,030
„ average per minute	revs.	58·58	58·38
Indicated Horse-power, mean	I.H.P.	119·131	120·757
Water pumped at 800 lbs. pressure per square inch, total during trial	gallons	106,293	105,931
„ average per minute	gallons	177·15	176·55
South Wales Coal fed into furnaces, total during trial, ash &c. not deducted	lbs.	2,354·51	2,192·47
Coal per Indicated horse-power per hour	lb.	1·97	1·81
„ „ Pump „ „	lbs.	2·37	2·22
Boiler pressure per square inch above atm.	lbs.	100	100

preserve their correct length. The whole of the work, including all the mains, was prepared in such a way that it was unnecessary to obtain any making-up pieces in Buenos Aires ; and all the machinery for each sump was erected in the workshops at Chester before being sent out.

It will be seen from Table 4 that the coal per indicated horse-power was 1·89 lbs. per hour, and per pump horse-power 2·29 lbs. per hour. Taking the average efficiency at the sewage pumps at 50 per cent.,* including all losses in the mains and valves at the highest speed contemplated, the expenditure of coal is 4·58 lbs. per pump horse-power at the sumps. This shows that 41 per cent. of the indicated horse-power of the engines is recovered in useful work at the sumps. The pumps have to work under most variable conditions, and are situated at seventeen sumps distributed over an area of nearly

* The actual efficiency of the pumps with the higher lifts of 20 to 28 feet was considerably more ; but at the lower heads of 10 to 15 feet the efficiency was necessarily reduced.

two square miles, requiring over eight miles of mains to connect them with the central station. The economy to be obtained under such circumstances cannot be great; and it is believed that no other method of distribution has shown such good results under similar conditions. The Hydraulic Engineering Company, Chester, were the contractors for the construction and erection of the whole of the plant; Mr. F. W. Thornton had charge of the erection of the machinery and laying of the mains for them.

Hydraulic pumps of the same kind as those at Buenos Aires have been for some years at work, pumping the water from the river Thames into the reservoir tanks at the London Hydraulic Supply stations. At Falcon Wharf, Blackfriars, the head is about 80 feet, including friction in the rising main; and the efficiency of the pumps is $75\frac{1}{2}$ per cent.

Discussion.

Mr. Ellington exhibited a collection of samples of broken and otherwise damaged pipes and bolts. Among these was a nut, of which a large portion had been cut away. The abrasion was all done in two hours by a small escape of water from a crack in the pressure pipe. In Eastcheap, London, when the New River Water Co. were repairing one of their mains, the pressure pipe to which the bolt was applied was exposed, and gave way while the men were working in the trench. It was an hour and a half or two hours before the pressure water could be shut off. When the nut was taken out, it was in the abraded condition now shown. There was another curious thing about that occurrence. When the ground was opened up, so that the line of pressure pipe was free, there was a space of one foot vertically between the two ends previously bolted together. The pipe had originally been laid quite level, but

(Mr. Ellington.)
the strain due to settlement of the roadway had been so great that it had bent the pipe down till it broke; and it had to be repaired by putting in an S bend to make up the length.

The Honourable R. C. Parsons mentioned that a paper would shortly be read before the Institution of Civil Engineers, which would give a detailed account of the sanitary improvement works carried out at Buenos Aires during the last twenty years, on which rather more than six millions sterling had been expended. The drainage, of which an account had been given in the present paper, was only a small portion of the entire drainage of Buenos Aires. It was that of a low-lying district on the borders of the river Plate, where the surface of the ground was only a few feet above the level of the river. The whole of the area was at times covered with water; but in spite of this the Argentines had insisted on building their houses upon the marsh, and it was therefore necessary to drain the district by some method. It was a difficult work, and had been put off till the last, so as to devise the most suitable arrangement for dealing with it satisfactorily, as he thought had now been done by the plan described in the paper. The ground of the entire district was a running sand laden with water; and it was impossible to lay the sewers more than from 8 to 9 feet below the surface. It was therefore absolutely necessary to divide the district up into the large number of pumping stations which had been mentioned, namely seventeen; and the length of the sewers had to be kept within certain limits, in order to obtain an efficient flushing velocity, and at the same time avoid going more than the above mentioned depth below the surface. Those were the conditions that presented themselves when the matter came to be dealt with. It was then necessary, as there were seventeen pumping stations, to devise the best means of working them: whether by supplying motive power to them all from a single central pumping station, or by generating the motive power at each separately. The first method that suggested itself was compressed air, which had already been used in more than one instance by Mr. Shone for sewage pumping. Then there was electrical distribution of power. There was also

the possible means of sucking the sewage to a central station. Electrical power was soon disposed of, principally for the reason already hinted in the paper (pages 366 and 371), namely that the employment of electricity involved high-speed machinery, which had to be reduced down to the slow speed necessary for working the sewage pumps. It was also necessary to have a compact system, as would be seen from Figs. 43 to 45, Plate 94, inasmuch as it was necessary to put the pumping stations in the centres of the streets at their crossings, so as to avoid any unnecessary bends in the sewers. The suction and compressed-air methods were also carefully considered, especially in regard to economy, as the power required to pump the sewage of the district amounted to about 150 horse-power. In the case of the compressed-air method, the efficiency was considered to be too low to warrant its adoption. One reason for this was the impossibility of compressing air along the isothermal curve; the compression therefore involved considerable superheating of the compressed air, and the heat gradually leaked out until the air was reduced to the surrounding temperature. This was one of the great sources of loss in the use of compressed air. The next was that with such a number of pumping stations as seventeen there must necessarily be a corresponding variation in the lifts from the several stations, because in an area like the district in question, which was practically level throughout, the lengths of the sewers connecting the several stations with the outfall sewer were almost all different, and consequently the friction in each was different, and could not be made the same in all, as there must be a flushing velocity in all the sewers, or they would become furred up with sewage. If compressed air were used, it would have to be at the same pressure in all the different pumping stations throughout the district, and the pressure would have to be that necessary for the highest lift; there would consequently be a considerable loss in the larger number of them, because one station required one pressure, and another another. These were a few of the principal drawbacks to the use of compressed air for such a system of drainage. Hydraulic distribution of the power was then carefully considered, and it appeared that this was the best suited to the requirements of

(The Hon. R. C. Parsons.)

the case. The next point was to find an arrangement of hydraulic pumping machinery which could be put up easily in the centre of the streets. The details of the hydraulic pumps here used had been worked out under the advice of Mr. Ellington when the tender of the Chester Hydraulic Engineering Co. had been accepted, a large number of firms having been invited to tender for the work. In regard to the push-back rams, shown in Plate 95, there was of course a considerable amount of friction in letting the water run into the push-back cylinders and afterwards forcing it out again, as had to be done at every stroke, as well as friction of the rams themselves. As a means of avoiding the consequent loss, it had naturally occurred to him in the first instance that, as a constant force was necessary to raise the large ram in each upward stroke, this should be done by means of a balance weight, as in mining machinery; but in the present instance it was necessary to have as compact a form of pump as possible, and the two push-back rams formed the most compact arrangement that could be devised. From a careful calculation of the efficiency of the system he had found it came out rather less than the 41 per cent. given in page 374 of the paper; he believed it did not really exceed 38 per cent.; but not more than 20 per cent. could have been obtained if a compressed-air system had been adopted.

Mr. J. F. L. Crosland noticed it was mentioned in page 355 of the paper that there were five Lancashire boilers in Manchester, $7\frac{1}{2}$ feet diameter and 30 feet long, provided with two of Green's economisers containing 160 pipes each; while in Glasgow there were to be eight Lancashire boilers, 7 feet diameter and 30 feet long, four of which were to be provided with two economisers of 160 pipes each. Further on it was remarked that it would be interesting to compare the result of the working of the Glasgow boilers with that of the boiler described as the Fairbairn-Beeley boiler, shown in Plate 89. The number of economiser pipes supplied to the boilers in Manchester and Glasgow he considered was not sufficient for their size. For the five boilers in Manchester there should have been 400 pipes, and for the eight in Glasgow, if four only were used at a time, about 300 pipes, or if

all eight were to be used at once, 600 pipes, in order to get the full advantage of the economiser. The reason for using so large an economiser was that time was required for enabling the spare heat to be taken up and to heat the water that passed through the pipes. If the economiser at Glasgow was enlarged, and other conditions, draught &c., were satisfactory, an evaporative power might be expected of about 9 lbs. of water per lb. of fuel. It must be borne in mind that the coke breeze used in Glasgow was not nearly so good as dry Nixon's coal of the calorific value of 15·5 lbs., which was about the best coal that could be obtained. Still a good result might be obtained, although not such a good result as that mentioned in the paper of 11·11 lbs. of water evaporated per lb. of coal from the temperature of 63½° Fahr., or 13·44 lbs. of water from 212°. These figures, he apprehended, were simply the results of a trial of the boiler and economiser when the amount of coal burnt must have been small. It would be seen from the drawing that the ratio of the fire-grate area to the heating surface was much less than in an ordinary Lancashire boiler. Such a boiler as this seemed to him to have defects of its own, one of which was the impossibility of examining it thoroughly, and of cleaning. It could therefore be used only with distilled water, unless the ends were so made that the flue and tubes could be removed bodily, as was the case with the Fairbairn boiler. The latter consisted of two ordinary single-flue boilers, supplemented by a steam receiver placed above them and common to both. It had been adopted by Sir William Fairbairn in 1870, in order to use a pressure of 150 lbs. per square inch in the triple-expansion engines he was then making from the designs of J. S. Crosland of Manchester. In this form of boiler there was no novelty, as the single flue terminating in a multitubular arrangement had been designed by Schofield in 1852, and the general arrangement by Lawes in the same year. The boiler now described and shown in the drawing was therefore in no way the boiler which was known as the Fairbairn boiler. Although its evaporative power would no doubt be great, he thought it was not a suitable boiler for the purpose for which it was here used; and for ease of repair and all other practical considerations he should have preferred a Lancashire

(Mr. J. F. L. Crosland.)
boiler. In actual working practice he had never met with anything like such an evaporation as that mentioned in the paper, although he was aware that in a trial it could be obtained by using the quality of fuel described. Of course if the combustion were made slow enough, and the ratio of fire-grate to heating surface sufficient, it could be got in a Lancashire boiler; but he wanted to know what was the evaporative power of such a boiler as that shown in the drawing under ordinary and regular working conditions.

Mr. Thomas Beeley said there were now at work some hundreds of boilers of the kind shown in Plate 89, several of which had been working since 1872. The plan had been devised by Sir William Fairbairn in conjunction with himself; and the first boiler they brought out had two fire-boxes and flues, which were attached to end plates of $1\frac{1}{4}$ inch thickness. In the original form it was found that, in consequence of the length of the boilers being only 14 feet, they were not economical, owing to the intense heat going from the ends of the flues into the chimney; with ordinary firing the temperature rose to something like 1,000° at the chimney end of the flues. There was also a good deal of trouble with priming; and it was on this subject that he had first become associated with Sir William Fairbairn in the design of the boiler. The method of preventing priming by the insertion of the uptake circulating pipes of D section, as shown in Fig. 33, had been suggested by himself. The steam generated in the lower cylinder of the boiler ran along its summit, and was directed up through these uptake pipes into the steam space of the upper cylinder, while the water fell by its own gravity into the water space, and returned thence into the lower cylinder. Up to that time the boiler had not worked well in consequence of priming, but these circulating pipes settled the difficulty; and the water was now as quiet as in any boiler that could be made, the priming being entirely done away with. Sir William Fairbairn had been desirous of introducing these as marine boilers; but their heating surface was not sufficient to allow of their being so used. The improvements effected by the introduction of a number of small tubes between the furnace and the end of the flue, as

shown in Fig. 33, had been suggested by himself. By this means the internal heating surface of the boiler was increased by no less than 350 per cent., and in consequence it was now well adapted for marine purposes, since it had a large furnace and heating surface, and was light as to material and water carried. It would also be noticed that at the lowest part of the tube-plates there was a tube much larger than the rest, which served the double purpose of giving facilities for raking flue dust out through it while the boiler was working, and of replacing, by a tube of larger draught-area, smaller tubes which would quickly make up with flue dust. Each end of the lower section of the boiler was made of a plate $1\frac{1}{4}$ inch thick, faced up like a cylinder cover, and reduced in thickness to $\frac{3}{4}$ inch between the shell and the flue, as shown in Figs. 36 and 37, so as to provide for expansion and contraction of the flue without disturbing the joint. On withdrawing the bolts which secured the combined furnace and tubes to the shell, this internal portion, which was fitted with a series of runners or grooved wheels, was received upon rails secured inside the bottom of the shell; then the whole combination was easily drawn out, and thus every part of the furnace, tubes, and shell, was open for examination and cleaning in good daylight. It was thus the best boiler of any in existence for cleaning, examining, or repairing if found necessary. The efficiency of the boiler, he considered, had nothing to do with the number of the economiser pipes; if 500 pipes were used when only 150 were necessary, there would of course be so many more to pay for. It was better to absorb the heat in the boiler itself, instead of carrying it forward into the chimney flue to be picked up there by an economiser. The setting of the boilers was so arranged for the absorption of the heat that at the foot of the chimney the temperature was no more than 200° F.; it would therefore be seen that at any rate good use was made of whatever heat was generated. One firm was now working thirty-three of these boilers, another twenty-one, and another sixteen, while there were many that had from five to ten; and they had all worked well. For a boiler like this he was sure the purchasers were too wise to pay more than they would for a Lancashire boiler, if they did not find there were advantages in it.

Mr. J. HARTLEY WICKSTEED, Vice-President, had been struck with the seemingly small matter of detail mentioned in page 358, with regard to the setting back of the flanges on the pipes at the joints. It seemed an interesting problem to account for the flanges that were set back from the ends of the pipes being found to be so much stronger in practice than flanges which were flush with the ends of the pipes. The slightly projecting end of the pipe he supposed had the effect of strutting the flange; and by calculation he imagined it would be found that the compression part of the set-back flange was much stronger, and therefore the flange would require more force to break it than if it were flush with the end of the pipe. It seemed also to come out in page 364 of the paper that there was another advantage in having the flanges set back, through their allowing then of longer bolts; because in the late severe winter, when water had ceased flowing through a dead end and froze, the pipes shrank; and as they would be practically anchored and fastened at each end, they strained and opened many of the joints in shrinking. Then the remarkable thing occurred that, on water of 60° being brought back into circulation, the pipes were restored to their original length, and most of the joints again became tight. This he thought would not have happened if the pipes had been bolted up with short bolts through flanges that came close to the ends of the pipes.

Venturing upon the larger question of hydraulic and electric distribution, the irregularity of the line in the diagram Fig. 30, Plate 87, showing the variations in the demand for hydraulic power, appeared to him to be inverse to the fluctuations that took place between the maximum and minimum requirements of electric-light consumers. It occurred to him therefore to suggest that, if the consumption of the hydraulic power were found to be going down where that of the electric current was going up, great economy might be realised by the use of the hydraulic power for generating electric current at times when the former was not being so largely used for the supply of power.

Mr. HENRY SMITH enquired what sort of valve was used in connection with the sewage-pump hydraulic motors shown in Plate 95.

Mr. H. W. Pearson asked if a statement could be given of the consumption of coal in regular work for twelve months, or even for six months. In page 357 it was mentioned that the water supply was drawn from the corporation mains; and he enquired whether the supply was obtained at the ordinary trade rate, or whether any special rate was charged to the Hydraulic Power Co. The ratio of efficiency in the London power supply, which was stated in page 359 to range from a maximum of 0·9826 down to a minimum of 0·8560, he supposed was the ratio that the consumption recorded by the meters —which, judging from the tests of such meters, he considered might be taken to register slow or against the company—bore to the delivery of the pumps, as calculated from the counters after deducting slip. Anyone who had had to do with meters knew that under so heavy a pressure there must be a certain amount of wear and tear; and in the meter shown in Plate 85 it was clear that the piston working upon a hub must on that account, combined with wear and tear, pass water to a certain extent without registration. In connection with the late severe frost, of which all hydraulic engineers had had more or less eventful experience, he asked what percentage of water was pumped to waste for maintaining the circulation during the frost. Nearly all water engineers he believed had found, as he himself had at Bristol, that during the frost the water consumption had gone up in the course of a week or ten days to double the normal amount, and had continued so for five or six weeks. It would be interesting to know whether water under these heavy pressures differed in its behaviour in this respect from water under ordinary water-works pressures. The registration of the water used by consumers he gathered from page 365 was effected on the exhaust or outlet side of the machinery, giving the consumer the benefit of all the leakages. But in some cases he understood from the same paragraph that the water was registered on the pressure side.

Mr. James M. Gale, Engineer of the Glasgow Corporation Water Works, said that the hydraulic installation at Glasgow had only been completed and brought into operation on the 30th May, so

(Mr. James M. Gale.)
that there had not yet been time to ascertain anything about the efficiency of the engines or the working generally; but in the hands of Messrs. Ellington and Woodall, who had designed the machinery, the Corporation had confidence that everything would turn out to be satisfactory. When the proposal was first made that there should be such an installation in Glasgow, some of the mechanical engineers of the city wished that the pressure should be at least 1,000 lbs. per square inch, with a view to employing it advantageously in their own works. That was a considerably higher pressure than had been employed in London or elsewhere; but it was represented that the advantage of the higher pressure would lead to its use in engineering shops. After it had been resolved to increase the pressure to 1,120 lbs. per square inch, it was gratifying to learn that this was the pressure which was being adopted also in Manchester. The two cities of Glasgow and Manchester had now a higher pressure therefore than any of the other cities mentioned in the paper. The size of the mains it was also important should be ample. In Manchester the internal diameter was six inches; but in Glasgow the facility with which cast-iron was attacked by the Loch Katrine water led him to wish that the size should be one inch larger, and Mr. Ellington saw no objection, seven inches being the internal diameter of some of the London mains. The higher pressure in Glasgow involved of course thicker pipes and stronger joints; but with these alterations the mains in Glasgow had been found perfectly successful thus far. About seven miles of pipes had been laid, and there had been no trouble with them, and no leakage. The origin of the hydraulic power supply in Glasgow had been the great dissatisfaction that was expressed by the users of hoists propelled by means of the gravitation supply in the streets. There were about six hundred of such hoists; and although the pressure might be put at 50 lbs. per square inch, there were seasons of the year and periods of the day when this pressure was not to be got, and when therefore the hoists could not be used. That naturally became a great grievance; and although from time to time additional pipes were laid from the service reservoir, and larger mains were laid in the streets, yet these were not sufficient to bring

about a satisfactory pressure for the working of the hoists. So convinced were some of the house proprietors in Glasgow that something more was wanted, that they started a private company to carry out the works themselves, at the head of which was Sir William Arrol; and no doubt they would have carried out the works, had it not been that at that juncture the Water Commissioners promised to undertake the duty themselves, and to establish the hydraulic power works which had just been completed and brought into operation.

Mr. Ralph H. Tweddell was sure no hydraulic engineer could listen to such a paper as the present without having something to say upon it; and to himself it was of particular interest, because the earliest inception of the plan of hydraulic power supply had been at Hull, where he had had the pleasure, together with another member of the Institution, Mr. Henry Chapman, of being associated with Mr. Ellington in the formation of that pioneer company, in which the carrying out of the scheme was due to Mr. Ellington alone. Now that the work of hydraulic power supply had assumed such gigantic proportions, he thought Mr. Ellington's name should be brought more prominently forward in connection with it than had been done by his modesty in the present paper. Although the plan now appeared so simple, twenty years ago when the Hull scheme was started it did not meet with much encouragement: it seemed a leap in the dark of the most momentous kind. It proved however to be a great leap in the most satisfactory sense, because the Hull works had paid steadily ever since; and he believed that from a financial point of view all such works, if the site were properly chosen, were certain to pay. Naturally he took great interest in the subject, and he congratulated the author on the practical results that had followed, which seemed like the realisation of Bramah's dream (Proceedings 1868, page 40); but it was a long stride from his dream to a supply of hydraulic power like that now carried out in Hull or London or Glasgow, in which the practical application of Bramah's principle was due to Mr. Ellington. He should be glad however to know why 1,120 lbs. or half a ton per square inch had been fixed upon for the water pressure in Manchester and Glasgow,

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instead of going to 1,500 lbs. which had been successfully used for a number of years in other applications. At the low pressure of 750 lbs. it had been mentioned in the discussion upon the author's last paper before the Institution of Civil Engineers (vol. cxv, 1893, page 247) that as a handy rule every two gallons pumped per minute represented one horse-power; but with 1,500 lbs. his own rule would be far better and simpler, namely one gallon for one horse-power.

In Table 1 (page 354) would be noticed the remarkable variation in the horse-power transmitted per mile. Omitting Antwerp as exceptional and Glasgow as not yet in full operation, it would be found that the average of the other seven came out about 48 I.H.P. per mile. It was 222 in Antwerp, which was eliminated; but in London, Liverpool, and Melbourne, curiously enough the figures were the same, namely about 45 I.H.P. per mile. Hull however averaged 100 I.H.P. per mile. Another interesting point to all engineers connected with the distribution of power was the average power required by users. Calculating again from the figures in Table 1, and omitting Antwerp, Birmingham, and Glasgow, for which the figures were not given, the average of the other six came out about 1·8 I.H.P. for each machine. He asked whether this conclusion was borne out in practice, from measurement of the average horse-power used. It was of great importance in works of this kind to settle beforehand what power the users were likely to want in a city like Glasgow; and it seemed to him that nearly 2 H.P. per machine was rather large for an average.

As to the application of power and the efficiency (page 359), his own opinion was that the advantage of high efficiency had often been altogether over-rated. It might be thought scientific to regard efficiency as the first object to be aimed at; but he considered technical efficiency might be bought at too high a price, and there must be good sound work done before there was any efficiency worth the name. The latter was not everything; and it might even be better to pay a little more for the work that was being done than to pay a little less. Users of power were willing to pay much more per thousand gallons for a supply which they could use just

when they wanted, than for a supply which they must take continuously whether they wanted it or not; they might pay fourpence per horse-power per hour for a supply used intermittently, that is, for power stored up in the accumulator ready to be used when wanted, but only one penny for a continuous supply.* In other words a higher price paid only while a machine was at work was more advantageous than a smaller sum charged continuously. The advantage of hydraulic machinery was that the user had to pay for the water only while the machinery was actually at work. The accumulator was the whole secret of the success of hydraulic machinery: the power was stored up, and could be utilised at any moment economically and expeditiously; it was just like a big balance at the bank, on which a cheque could be drawn when wanted. The accumulator was in truth the most economical factor in hydraulic machinery.

The graphic representation in Plate 90 of the figures given in Table 2 (page 368) appeared to him most remarkable. The first five items of the comparison between hydraulic power supply and electric supply, forming the upper portion of the diagram and the table, presented certainly a strikingly close coincidence. This ceased however in the other portion relating to the station costs, of which almost all the items in the hydraulic power supply fell considerably short of those in the electric supply: for salaries and wages the figures were £6,345 electric against £3,071 hydraulic; for repairs and maintenance £1,478 against £929; and the total station cost was £14,893 electric against £8,627 hydraulic. There must be some reason for this, and he should be glad to have some further information about the difference. While the first portion of the table was so closely identical, the capital outlay and the quantity sold being practically the same, yet in regard to cost there was as much as 40 per cent. difference, which appeared to him to be difficult to account for.

In regard to generating electricity by hydraulic power (page 366), it seemed that in order to drive a dynamo by hydraulic power, instead of direct, five operations at least would have to be gone through.

* Proceedings Inst. C.E. 1888, vol. xciv, page 17.

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There was first the steam engine, which was common to both plans; then the accumulator pumps, the friction through the hydraulic mains, the hydraulic motor, and lastly the dynamo. All these sources of loss had to be met before the work was done in the shape of electricity generated. Whereas an electric engineer would put the engine straight on to the dynamo, without anything between the two. The boiler of course, like the engine, was common to both plans. These considerations rendered it still more difficult to understand how electricity generated by hydraulic power could come out anything like as cheap as electricity generated direct; it seemed as though there must be some waste in electric transmission which did not exist in hydraulic. For the vast majority of work he thought there was a great deal more yet to be done by hydraulic power. From his own experience he knew that hydraulic power was the most economical in actual application; and Table 2 confirmed this view. There was absolute safety in hydraulic transmission, by the aid of which a great force could be exerted at any moment with only a small prime mover; whereas for electric transmission power must be provided equal to the greatest demand that could possibly be made upon it at any time. The present paper he considered was of great value to the Institution, containing a large amount of information such as all the members liked to get; and while it left electrical engineers to fill up some of the gaps, he was sure that many hydraulic engineers would be glad to hear what they had to say in explanation of the points to which he had drawn attention.

Mr. Thomas Clarkson believed he had been the first to put up in London a few years ago the Pelton wheel driven from the mains of the Hydraulic Power Co.; and the experience he had had of its working was that it was a troublesome motor to govern. It was found that there was a considerable variation not only in the load, but also in the actual water pressure. Sometimes the pressure was 750 lbs. per square inch, and sometimes it went down much below this, presumably when other consumers in the immediate vicinity were using the water. The way in which it was managed roughly to govern the speed was by throttling, which was equivalent to

reducing the pressure from the main; but he believed a better way would be to vary the area of the nozzle, if possible keeping the jet solid, and employing the full pressure. On the Pelton wheel shown in Plate 86, he noticed there was a governor acting upon a conical spindle, which was inserted in the nozzle, and was advanced or withdrawn so as to reduce or increase the effective area of the orifice, at the same time producing an annular jet. One reason for the high efficiency of the Pelton wheel he had understood was that a solid jet was employed, which impinged upon the knife edge in the centre of the bifurcated buckets; and he should therefore like to know whether the employment of the annular jet produced by this mode of governing would necessarily reduce the efficiency to any extent. It was commonly stated by the makers that the efficiency was about 85 per cent.; and if any tests had been made since the application of the governor, he should like to know whether the efficiency had been reduced thereby.

Mr. A. Tannett Walker, Member of Council, mentioned that, in connection with a large installation of hydraulic cranes and machinery, carried out by his firm at the port of Genoa, a commission had been sent there from Rome to test the efficiency of the machinery; and it had been found that water could be got into the accumulators at 750 lbs. per square inch with a loss of rather less than 15 per cent. Another interesting fact was that with plain ram pumps and good workmanship the rams were "drop" tight without the slightest leakage at any part, even when running at a moderate speed. Also in pumping out of one tank into another tank, the accumulator being at the top of its stroke and the pressure 750 lbs. per square inch, there was found to be a loss of only 4 per cent.; showing an efficiency of 96 per cent. Moreover the cranes could be worked at a speed of block hook of 360 feet per minute. Hitherto he had not met with any toolmaker or any electrical engineer, or both combined, who could produce a motor and a range of gearing, by which either with steam power or with electricity the work could be done as cheaply and as effectively as with water. Having constructed cranes of almost every kind, his

(Mr. A. Tannett Walker.)
firm had been obliged to make the geared wheels of forged steel and to cut the teeth by machinery, in order to get anything like a proper efficiency. For an ordinary crane to lift 30 cwts. and to discharge from 70 to 80 tons an hour, he should much like to see an arrangement of gearing that would do what a hydraulic crane would do, and that would produce a speed of block hook of 360 feet a minute without noise.

Mr. T. HURRY RICHES, Member of Council, said that fifteen or sixteen years ago, having a good deal of hydraulic power available, he had tried the experiment of driving some electric-light machinery by what was known as the Hastie engine (Proceedings 1879 page 484), running at 400 revolutions per minute. The difficulty had always been the fluctuation of the load on the dynamo, and the corresponding governing of the engine at that high speed. He had tried several governors, and had made a great many experiments to endeavour to govern the engine satisfactorily. It was indeed supposed to be automatically governed by the lengthening or shortening of the stroke, under the action of a spiral spring contained within a cylindrical case on the crank-shaft; but although it worked fairly well for a short time, he found it soon got out of order; it was not sufficiently steady to give a constant spark or a constant current in the dynamo. Consequently the light became rapidly defective. He had then tried what was shown in the drawing of the Pelton wheel, Plate 86, namely a cone valve which converted the flow of water from a solid into an annular stream; but he found that the efficiency of the latter was not so great. After a great many experiments he had practically given up the use of that kind of engine for driving dynamos.

The PRESIDENT said that by the courtesy of the author he had seen the paper before it was printed, and he had naturally examined Table 2 closely. He had not been able to find any error in it; the figures there given he believed were quite correct and fairly put. The table certainly surprised him in its results, as he had no doubt it had surprised the author himself when he worked it out; and

naturally each wanted to try to find out where the difference came in between the work of the electric supply and of the hydraulic supply, both in the same city, and under conditions which were so singularly alike. He thought however that he saw where some of the difference lay; and should be glad to offer his own view, in order that he might hear what Mr. Ellington had to say about it. Practically the boilers were equally economical in both cases ; and the engines in themselves, when working at full load, were also equally economical, as far as he knew ; in both instances they were good. In the electric supply more than half their work was done without condensation, which of course accounted for a certain portion of the difference in the coal bill, though not nearly all. About five-eighths of last year's work of the Westminster electric supply, if not three-fourths, was done without condensation ; and it was easy to see what a difference this would make in the coal bill. He thought however that there was another cause, and a very interesting one, which would account for the remainder of the difference in the coal bill. It had been mentioned in the paper (page 369) that it was managed in the electric station to run the machinery actually in use at nearly full load. This he was afraid was putting it much too favourably. Last week, for instance, at the three stations of the Westminster company the load factor—taken as the ratio of the work actually done to the maximum work which could have been done by the same engines in the same time, if each working at full power—was nearly 80 per cent. at one, about 70 per cent. at another, and only 55 per cent. at the third. This was the best the stations had been able to do : so that, as a matter of fact, with all their endeavours they did not nearly run at full load. Moreover—and here he believed was the secret of the matter—while not running at full load they still ran at full speed. With hydraulic power, unless he was mistaken, the speed of the engines practically altered with the work : so that, if they were making 50 revolutions per minute at full speed, then if the work went down to half they made 25, and if to a quarter $12\frac{1}{2}$, and so on. When the speed altered with the load, the waste of power in driving the engines and pumps continued to bear the same constant proportion to the total power ; whereas when the speed remained

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constant under a varying load, and the engines were running always at full speed, the work of driving the engine and dynamo and all the friction remained the same absolute amount, and therefore it bore an increasing proportion to the total power as the load went down. Hence he thought that the absence of condensation in the electric engines, and the fact that the hydraulic engines could work in the fashion he had mentioned, accounted for the main difference in the coal bill. It should be added that, at two of the electric stations in question, which were in the centre of fashionable residential districts, the absolute absence of smoke was a necessity, not felt at the hydraulic power stations, and consequently Welsh coal only was used; and in any case the cost of fuel at these stations was sensibly increased by the expense of cartage.

The difference in the item of salaries in Table 2 was certainly large in the total; but it would be necessary to divide by the number of men, and see what the average came out. The difference in the total he supposed was mainly due to the fact that the dynamos and the engines driving them required considerably more looking after than the pumping engines; he could not account for it in any other way. In the electric station it was necessary to have skilled men at the switchboard, looking after the regulation continuously; and there was practically always a skilled engineer in charge of the station. The work was of a more complicated kind, at any rate at present; perhaps later on, when the industry became older, it might be so far simplified. When any of the members came to work out, as he was sure they would do, further results from the figures given in Table 2, they would be able to get at the approximate value for the coal per indicated horse-power per hour, assuming of course certain efficiencies, for which they could take approximate quantities. If Mr. Ellington would state the price given for the coal, they would then be able to work out approximately the number of pounds of coal per I.H.P. per hour. He believed it was somewhere about 2 lbs. per I.H.P. per hour, year in and year out, including all losses through banking, making up fires, cleaning fires, and everything. The pumping engines were not like marine engines working all day and all night; but sometimes they were working very little and sometimes

at full speed. So low a consumption under these conditions was most remarkable: all engineers would do their best to emulate it.

In connection with Table 2 it might further be mentioned that, although in the first half the two industries seemed to be as exactly equal as possible, and although in the second half the station costs of the electric industry amounted to a great deal more per unit, yet the actual dividends paid on the capital of the two companies seemed to be about the same amount: so that there was some further explanation to come in somewhere. It might be that the hydraulic company paid a much larger proportion of capital expenditure out of revenue: a course to which he certainly would hint no objection.

In page 359 were given some interesting figures of hydraulic-power efficiencies during a number of years. As the author had afterwards made a comparison with electric work, it ought perhaps to be pointed out that what was compared in page 359—namely the ratio of the water registered by meters to the water pumped—would in electric language be called "ampère efficiency," that is, quantity efficiency, and not energy efficiency. It was based on the assumption that the water pressure was the same at the consumers' terminals as it was at the accumulator. What the actual difference of pressure was, he did not know; but there must of course be some difference through loss of pressure by friction in the pipes. In a direct-current electric station the actual loss corresponding with that given in the paper—that is, the amount of current which could not be accounted for, the difference in meter readings, &c.—amounted to $1\frac{1}{2}$ or 2 per cent. on the whole quantity delivered; but of course the station efficiency was not therefore $98\frac{1}{2}$ or 98 per cent., because there was a further 8 or 9 per cent. which corresponded with the loss due to the resistance of the mains, bringing down the total efficiency to what he had found in the case of Westminster to be 88 per cent. This meant that 12 per cent. was lost either through differences of meter readings, or through energy expended in forcing the current through the mains, if he might use the equivalent of ordinary hydraulic language. One thing it was only fair to the electrical stations to say. In page 367 it had been pointed out how a single station might be somewhat more economical than the average of several; and in

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the particular instance of the Wapping pumping station it came out that this station was 20 per cent. more economical than the whole hydraulic supply. In the electric supply however it happened that there was but little difference between the most economical station and the average of all; in the Davies Street station the station cost was equivalent to $8\frac{3}{4}d.$ per thousand gallons as against $9d.$ for the whole supply. Such a comparison however could hardly be made fairly in this particular instance, because the Davies Street station was one which did about half the whole work of the entire electric supply, and the engines were there working non-condensing, so that there was a saving in wages and a loss on coal: in reality the three electric stations were approximately equal in their costs per unit, and the bigger did not from being bigger get more advantage than was made up for by other matters. The average comparison of all the three together against the whole hydraulic supply, which had been made in Table 2, was perfectly fair and legitimate.

He was sure the members would agree with him that Mr. Ellington's paper was a most able and admirable one, the treatment of the subject being at once scientific, clear, and impartial; and that the author was entitled to a hearty vote of thanks from them.

Mr. ELLINGTON said he had naturally followed somewhat closely the question of electrical distribution, especially with regard to cost. It had always seemed to him, from the time when he first saw the results of the experiments made upon dynamo-driving, that there should be no material difference between the cost of the two supplies, using a common standard for the energy generated, and irrespective of the cost of distribution through the mains; therefore he was the more surprised to find such astonishing discrepancies in the actual station costs. When he first drew attention to the fact at the Institution of Civil Engineers (Proceedings 1891, vol. cvi, page 57) in the course of the discussion upon Mr. Crompton's paper on the cost of the generation and distribution of electrical energy, the late Mr. Willans had answered him (page 60) as the President had just done, by saying that it was the varying speed of the hydraulic pumping engines which accounted for the difference of cost. At that

time he had pointed out (page 57) that the cost of producing the electric energy was nearly double that of the hydraulic. The answer was no doubt correct in regard to the engines: the speed of the pumping engines went down to nil when there was no demand; that is, there was an actual stoppage. At the Falcon Wharf station, upon which as the central station the variations of demand more particularly came, it occasionally happened that all the engines stopped automatically and started again from time to time for keeping up the supply. The maximum speed ran up to 55 or 60 revolutions per minute; but the average speed of each engine running was certainly not more than 70 per cent. of the maximum—probably considerably less, taking the twenty-four hours. The difficulty he had found in accepting as complete the explanation in regard to speed was that, when he examined the figures which had been given fifteen months ago in the presidential address of Professor Kennedy (Proceedings 1894, pages 203–6), it appeared that the losses due to light loading of the engines in electric stations were not more than the losses which had been actually measured as due to intermittent working of the hydraulic pumping engines. The best pumping stations certainly did not get on the average more than two-thirds of the value of the coal in work done, as compared with the results obtained under the most economical conditions (Proceedings Inst. C.E., 1893, vol. cxv, page 228). The hydraulic stations had to keep up steam in the boilers, ready for the maximum demand; the fires were never let out at any of the stations, and the stand-by and steam-pipe losses were large, amounting in the London stations to at least 12 per cent.;—12 per cent. of the whole coal was burnt in keeping up the steam and keeping the pipes and jackets hot, when there was practically no work doing at all. In addition to this loss, there was about 20 per cent. due to intermittent running, that is, to running at less than the full speed of trials. A large portion of this loss should perhaps be included in the stand-by and steam-pipe losses, raising them to say 20 per cent. The losses in driving a dynamo at half load he believed were about 10 per cent. more than at full load; stand-by losses at the electric lighting station had been put down at 10 per cent.; and a similar amount

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for the steam-pipe condensation &c. When all the losses were added together, it would be found that the total loss from these causes was practically the same as it was in the hydraulic pumping station. He therefore did not feel that a complete explanation had yet been arrived at. There were certain items that were easily accounted for. Of the three electrical stations in the Westminster supply two were inland, away from the river; and the third was close by the river, namely the Millbank station. This meant therefore cartage of the coal to the other two; and he thought that about 10 per cent. of the whole cost of the coal might be put down to that increase. Then there was the fact that a large proportion of the electric engines were non-condensing. A comparison of the £5,842 cost of fuel for the total electric supply with the £3,263 cost of fuel for Davies Street station alone, as given in Table 2, would show approximately how much was lost by non-condensation; it might possibly be a further 10 or 12 per cent. Thus about half the difference in the cost of coal was accounted for. It had been suggested that the remaining difference might be in the cost of the coal itself. The coal burnt at the pumping stations in London was small north-country coal, and its value, delivered into the bunkers at all the stations, was a trifle over ten shillings a ton. The Westminster electric stations, he was informed by the President, burnt Welsh coal, of the quality known as "through and through," of which the average cost was 17*s.* 4*d.*, and the cost at Millbank was 15*s.* 10*d.* a ton. There might have been some slight increase due to the strike last year; and supposing this to be the case, the average might be taken at 15*s.* per ton. Then in order to secure equally economical results, after making allowance for the larger waste in using small coal and the expense incidental to handling a larger quantity, say one-third more work ought to be got out of the Welsh coal than out of the small north-country coal; and the question was whether this was accomplished. In the experiments he had made in burning Welsh coal at the pumping stations he had got a largely increased output, but not an increase equal to the difference in value. This he thought was partly accounted for by the fact that the mechanical stokers used

at the pumping stations were not well adapted for burning Welsh coal, which had been used only for testing purposes at the hydraulic stations in London. The records seemed to show that it was about 25 per cent. better than the small coal used in 1894. The explanation derived from the difference in the cost of the coal he thought was not satisfactory, because as a general result the Westminster electric station-costs were the lowest in the country, and under all conditions of coal supply in different places in the kingdom there was the same apparent excess of cost over the hydraulic supply. Another point to be observed was that the hydraulic stations had engines and boilers of 3,400 horse-power in the aggregate to maintain, whereas the electric stations had 5,000 horse-power; and this difference must count for something. After giving full weight to all the above sources of extra cost of fuel in the electric supply, there remained still some 20 or 25 per cent. difference which seemed to be not yet accounted for; and he wished to ask whether it was not to be found on the electrical side:—whether under all conditions of working the whole of the energy which ought to be obtained, or which was assumed to be obtained, really was accurately measured from the output of the dynamo. This was an electrical question, and he simply asked it as a suggestion towards a possible solution of the subject under consideration. The President had mentioned (Proceedings 1894, page 204) that he had on many occasions made experiments on running engines under the normal conditions of working, and that they had shown results agreeing with the original trials at different speeds. If those experiments had been made during times of full load at the stations, there would be nothing in his suggestion; but it seemed to him possible that in a large station, with a great deal of power running and a great number of dynamos, there might arise such a condition of electrical disturbance in the station itself as to get rid of a certain amount of power wastefully. He did not know whether anything of the kind occurred or not: at any rate he did not see how otherwise to account for the difference in coal consumption. Before leaving this matter he should like to point out that the extra cost of working stations involving cartage of coal and non-condensing engines was really

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part of the cost appertaining to distribution, for which an equivalent was obtained. While affording an explanation of part of the additional cost of fuel used in the electric stations as compared with the hydraulic, the desirability of establishing the electric stations so close to their work seemed also to indicate a permanent advantage in the hydraulic method, as claimed by Van Rysselberghe.

With regard to the financial question of dividends, it might be mentioned that in other items of cost there was a somewhat similar difference to that in coal: the establishment charges of the hydraulic supply were less than the establishment charges of the electric supply, notwithstanding a much greater amount of rating on the hydraulic supply. But in this respect he thought there was not any ground for comparison between the two; because, although it would be seen from the plan, Plate 97, that the hydraulic revenue was collected over an area five times as great as that of the Westminster electric supply, yet it was collected from a comparatively small number of consumers: so that the establishment charges were likely to be less, and were actually less. The result as to dividends was partly due to the fact that the Liverpool capital was mixed up with the London, the two concerns being all under the same control; and unfortunately Liverpool at present paid only about $2\frac{1}{2}$ per cent., while the total dividend over the two undertakings was $6\frac{1}{4}$ per cent., as against 5 per cent. for the Westminster electric supply. The difference of station costs shown in Table 2 really appeared as additional net profit earned.

With the President's remarks (page 393) as to the ratios of efficiency given in page 359 he quite agreed; and therefore no comparison had been attempted between the 93 per cent. delivery registered in the hydraulic supply and any electrical measurement. Payment had actually been received for the quantity registered as delivered, and no question of loss of pressure had entered into the amount of the payment. In this respect he imagined there was some difference between the electrical supply and the hydraulic.

The President explained that the electric current was required by law to be maintained at not less than a certain voltage or

pressure, as supplied to the consumer; and therefore the meters registered only the ampères or actual quantity delivered, and gave no indication of the voltage or pressure.

Mr. Ellington said that, this being the case, the measurements of the two supplies seemed to be on a par with each other, apart from the consideration of losses of energy in the mains. In the figures given for the London hydraulic supply the pressure was assumed to be 750 lbs. at the stations; but as a matter of fact the three pumping stations outside the central Falcon Wharf station were pumping most of the day at 800 lbs. per square inch, and he had omitted from consideration the extra 50 lbs. Therefore if the figures were corrected, the assumed pressure of 750 lbs. would be somewhat increased, and there would be a larger output of energy at the same cost.

As to the average horse-power taken per mile and per machine, which had been deduced by Mr. Tweddell (page 386) from Table 1, he should be glad if he could give any rule; but there was no possibility of doing so. In each respect there might be all kinds of variations in the same district. In Hull the supply was almost entirely confined to the power required in the wharves and warehouses alongside the old harbour. The amount of goods going in and out of river-side premises might be taken to be much greater than in the case of warehouses in towns. This accounted for the large amount of power from the machines in Hull. But unfortunately the work was more intermittent: so that, while the machines were taking a great deal of power at one time, they took a small amount at another; consequently the horse-power required at the central station was much larger in proportion to the number of machines. In London he had gone carefully into the question of the power required for individual consumers, having been led to do so mainly in order to see whether there was justification for the sliding scale of charges which was in operation in London and in other towns for hydraulic supply. There seemed to be a great difference between 5*s.* or 6*s.* per thousand gallons for small supplies, and 1*s.* 6*d.* for large consumptions. One of the factors in the problem was the horse-

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power needed, as affecting the capital outlay required to supply individual consumers. The quantity of power required at the central station he found to vary from $\frac{1}{4}$ H.P. per machine for a small consumer up to $1\frac{1}{2}$ H.P. for the larger consumers: that is, irrespective of any amount of power at the central station which might be required as a stand-by. It would be seen from Table 1 that in London 3,400 H.P. was provided at the present time for working 2,300 machines. The same amount of power would almost certainly work 2,550 machines, and the proportion would then be 34 to $25\frac{1}{2}$: that is, about $1\frac{1}{3}$ H.P. as the average per machine.

In reply to the enquiry why 1,500 lbs. pressure per square inch was not used (page 386), the reason for adopting 1,120 lbs. in Manchester and Glasgow had been given in the paper. Reasons of a similar character determined the pressure used in other towns. He had found a pressure of 800 lbs. quite high enough for most purposes. With a supply at a pressure of 1,500 lbs. per square inch there would be a good deal of difficulty in meeting the requirements of small consumers.

With regard to the Pelton wheel (page 389), he believed the makers had never claimed more than 80 per cent. efficiency. The Pelton company he expected had estimated the efficiency of the wheel itself, and had not allowed for the loss in the nozzle. But with such small jets there was a loss of 10 per cent. in the nozzles, and the net efficiency would therefore be only about 72 per cent. The governing apparatus certainly did somewhat further reduce the efficiency. The result of the Chester experiments (page 366) was not sufficiently detailed for enabling him to say exactly what the reduction was; but with a partially throttled nozzle there must be a loss of efficiency. The governor itself worked fairly well. It had not been tried in connection with the driving of the dynamo for any length of time; and whether or not it would be sufficiently sensitive for direct driving, that is, without accumulators, he did not know. This kind of apparatus he did not anticipate would be largely used in competition with any ordinary electric supply; but in districts where there was no electric supply, and where the demand was not of such a nature that it was likely to

be provided, and where hydraulic power was already available, the apparatus might be used with great economy. In regard to the variation in pressure, observed by Mr. Clarkson (page 388), the observations had no doubt been made near the nozzle, and the variation in pressure would be primarily due to the throttling in the supply pipes. No great variation of pressure occurred in the street mains; if it did, nearly all the machines in use would cease to work.

As to the use of the Hastie engine (page 390) for driving a dynamo, that engine was not really a governor at all. What the automatic gear did was to lengthen or shorten the stroke of the piston; but the quantity of water flowing through the engine per minute was practically the same, whether the stroke was long or short. The only effect of lightening the load was to shorten the stroke, and to increase the number of revolutions per minute. When the Hastie gear was applied to a hoist, it answered well; but for a continuous running motor it did not produce any effect, and no doubt this was the reason why the governing arrangement tried by Mr. Riches for the dynamo did not act.

The valves for the hydraulic sewage pumps (page 382) were ordinary slide-valves with one or two special modifications to suit the circumstances; they were made of gun-metal, and worked on faces of lignum vitæ.

Mr. William Schönheyder wrote that he fully agreed with the author's recommendations (page 359) as to the frequent reading of meters, say every month or every two months; a meter, being a machine, must necessarily be subject to wear and tear and accidents. The cause of the great increase in the minimum flow he could fully understand was to be found in the meters and in the consumers' machinery (page 361); and for this reason the best positive meters should alone be used, and should always be fixed on the pressure side, so as entirely to avoid the entry of the hydraulic-power men into the premises of the consumers, and any possibility of their interference with the users' machinery. The high-pressure water should in fact be sold in the same manner as low-pressure water or gas; and the user should have full liberty to waste as much as he pleased.

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Having had some eight years' experience in the manufacture and use of meters for ordinary waterworks purposes, as well as for measuring hydraulic supply at 700 to 800 lbs. pressure per square inch, the writer has not found the three disadvantages to exist, with which in page 365 the positive meter is charged. By proper design these alleged disadvantages can readily be avoided; and the difficulties mentioned with the counters of hydraulic meters he has never met with. Some of his own hydraulic meters have been in successful operation over four years; the first was made and satisfactorily worked in 1889, and he believes was the first meter used for such high pressures. To the statement that a meter after passing 1,000,000 gallons has been found under test still accurate within 1 per cent. (page 366) should be added the size of the meter, and the time it took to pass this quantity, as well as the rate of delivery when tested.

Professor W. H. Watkinson wrote—in regard to the conclusion (page 367) that for some reason or other, not hitherto explained, hydraulic power is much less costly to produce than electricity—that the capital outlay given in Table 2 for the two agencies is practically the same; and the important differences in station costs are for coal, which costs 80 per cent. more with electricity; for salaries and wages, which amount to 108 per cent. more; and for repairs and maintenance, which cost 60 per cent. more, and at the Davies Street station 114 per cent. more than at Wapping. The much higher expenditure on salaries and repairs is important, but easily understood, and he believes will soon be greatly and almost automatically reduced; and therefore the great difference in the consumption of coal for the same amount of energy is the point deserving of most attention. When working at full load it is probable that the engines used at the electric stations are more efficient than those at the hydraulic; but there is a most important difference between the two methods of working at light loads. At the electric stations the efficiency of the engines is greatly reduced at light loads, on account of the increased initial condensation of steam in the cylinders when the governing is by variable expansion,

and on account of the reduced range of pressure when the governing is by throttling. At the hydraulic stations the engines usually either work at full load or stop altogether, owing to the action of the accumulators; consequently, if the cylinders are steam-jacketed, there is no additional initial condensation, and the only losses while standing are those due to radiation from the cylinder jackets. If this is the true explanation of the difference in coal consumption, it should serve to emphasize the desirability of superheating the steam in engines for electric stations.

Mr. Ellington wrote that he had stated in the paper that he considered the measurement of the water power supplied should if practicable take place on the pressure side. The more the high-pressure meters were perfected and cheapened, the sooner would this desirable result be brought about. He was not previously aware of what Mr. Schönheyder had done in this matter. It was in 1888 that the necessity first arose for using high-pressure meters in London; and the first of such meters made for the London Hydraulic Power Supply was constructed by Messrs. Kent under his own direction. The meters first made had 2-inch inlets, and passed a maximum of 10,000 gallons per hour. The meters mentioned in the paper as having passed 1,000,000 gallons had been at work six months, and were then substantially correct at full flow. The Kent high-pressure meter which had been fixed in December 1889 had been taken out in May 1892; it had then passed 20,000,000 gallons, and was still found correct at full flow, 4 per cent. slow at 600 gallons per hour, and would not register a fine flow.

With regard to Professor Watkinson's remarks, it need only be added to what had already been stated that the hydraulic pumping engines did not as a rule run at full speed and then stop altogether. The work upon the different engines at the different stations was arranged so that they should run automatically at from about half to full speed. Automatic starting and stopping was avoided as far as possible.

RECENT ENGINEERING IMPROVEMENTS OF THE CLYDE NAVIGATION.

By Mr. JAMES DEAS, Engineer of the Clyde Navigation.

In a previous paper presented to the Edinburgh Meeting of this Institution in 1887 the author traced the improvement of the Clyde Navigation above Port Glasgow to that date. The object of the present paper is to continue the subject, by giving particulars of the dredging machinery, and especially of the recent additions thereto, and the quantities and cost of the dredging in the harbour and river, and the depositing of the dredged material, during the seven years from 1st July 1887 to 30th June 1894; and to describe in some detail the harbour of Glasgow and its equipment at the present day. See Plates 98 to 101.

Dredging.—The improvement of the Clyde above Port Glasgow since 1887 has consisted solely in deepening and widening by dredging. During these seven years the total quantity of material dredged in the harbour and river, and in the construction of the docks and removal of silt from them, was 11,401,978 cubic yards, of which 5,723,157 were deposit, and 5,678,821 were new material. In addition there were excavated by men 21,726 cubic yards, bringing up the total to 11,423,704, of which 441,850 were deposited on land, 9,523,141 in Loch Long, 1,449,243 in the sea three miles S.S.W. from Garroch Head, which is about 46 miles from Glasgow, and 9,470 cubic yards were deposited in other parts of the river and Firth or were otherwise disposed of. The details are given in the accompanying Tables 1 and 2. In Plate 101 are shown the sites of depositing in Loch Long and outside Garroch Head.

TABLE 1.—*Dredging and Excavating.*

Year ending 30 June.		1888	1889	1890	1891	1892	1893	1894	Totals.
		Cub. yards.	Cub. yards.	Cub. yards.	Cub. yards.	Cub. yards.	Cub. yards.	Cub. yards.	Cub. yards.
In Harbour and Docks	D	282,960	403,804	323,348	394,624	531,672	366,998	974,523	3,277,929
	N	18,720	117,836	43,276	46,848	411,824	1,168,484	1,032,017	2,839,005
In River, west of Kelvin	D	305,664	359,164	505,676	509,192	292,424	124,788	272,896	2,369,804
	N	711,440	602,236	485,292	288,856	239,824	66,856	14,232	2,408,736
On Loan account — In Harbour	D						1,472	32	1,504
	N			2,640	16,800	7,520			26,960
On Loan account — In River	D	17,280		15,840	5,920		17,600	17,280	73,920
	N	76,840	47,520	37,440	31,440	115,720	95,160		404,120
Totals Dredged		1,412,904	1,530,560	1,413,512	1,293,680	1,598,984	1,841,358	2,310,980	11,401,978
Excavated by men at various places		2,584	2,192	1,600	896	4,968	2,498	6,988	21,726
Totals Dredged and Excavated		1,415,488	1,532,752	1,415,112	1,294,576	1,603,952	1,843,856	2,317,968	11,423,704

D = Deposit. N = New material.

TABLE 2.—*Depositing of Material Dredged and Excavated.*

Year ending 30 June.	1888	1889	1890	1891	1892	1893	1894	Totals.
	Cub. yards.	Cub. yards.	Cub. yards.	Cub. yards.	Cub. yards.	Cub. yards.	Cub. yards.	Cub. yards.
On Land	70,168	62,112	45,392	57,840	65,592	86,176	54,570	441,850
In Loch Long	1,310,840	1,470,160	1,367,840	1,236,736	1,538,200	1,540,120	1,029,245	9,523,141
Off Garroch Head	—	—	—	—	—	217,420	1,231,823	1,449,243
In other parts of River and Firth, or otherwise disposed of	4,480	480	1,880	—	160	140	2,330	9,470
Totals Deposited	1,415,488	1,532,752	1,415,112	1,294,576	1,603,952	1,843,856	2,317,968	11,423,704

The cost of dredging and depositing by hopper barges, and of laying dredgings on land, during the same seven years—comprising wages, coals, stores, repairs of plant &c., but not including interest on cost of plant, or depreciation—was as follows, being equal to 6·396 pence per cubic yard :—

Year ending 30 June.	Cost. £	s.	d.	Quantities Dredged. Cubic Yards.
1888	44,128	6	6	1,412,904
1889	41,520	3	3	1,530,560
1890	39,914	0	7	1,413,512
1891	38,611	0	0	1,293,680
1892	40,268	13	7	1,598,984
1893	49,146	11	2	1,841,358
1894	50,292	6	2	2,310,980
	£303,881	1	3	11,401,978

Up till 1862 the whole of the dredged material was loaded on punts, carrying 8 cubic yards; and from these it was discharged, chiefly under contract, upon land adjoining the river, and also by throwing overboard on both shores at certain places below Dumbarton Castle, Plate 100. The average cost for thus depositing harbour dredgings, including the use of punts, towing &c., was 10·04 pence per ton, or $12\frac{1}{2}$ pence per cubic yard. The total quantity dredged for the year ending 30 June 1862 was 569,016 cubic yards, all of which was deposited on land.

In August 1862 depositing in Loch Long, within an area of 428 acres laid down by the Admiralty on a chart, Plate 101, was inaugurated by a steam hopper-barge built by Messrs. William Simons and Co., Renfrew, of 240 cubic yards capacity and 35 nominal horse-power. The barges were from time to time increased in number, until in August 1877 the fleet consisted of eighteen, four having a capacity of 240 cubic yards each, and fourteen of 320 cubic yards. The other dredging plant at that date consisted of five steam dredgers from 25 to 75 nominal horse-power, one tug steamer, two diving bells, and 250 punts. The total quantity dredged during the year ending 30 June 1877 was 965,468 cubic yards. In August

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1889, No. 6 dredger was run into, sunk, and wrecked in the river, below Bowling; and was not replaced until 1892, when a single-ladder dredger was procured, 200 feet long by 37 feet broad and 12½ feet deep, with a hull of steel, thirty-five buckets of 22 cubic feet capacity each, capable of lifting at the rate of 600 tons per hour in 40 feet depth of water, and lighted throughout by electricity; and also two twin-screw hopper-barges of 1,000 tons capacity each, which were followed in 1893 by four twin-screw hopper-barges of 1,200 tons capacity each. The dredger and four of the hopper-barges were supplied by Messrs. Fleming and Ferguson, of Paisley, and the other two hopper-barges by Messrs. William Simons and Co., of Renfrew. This dredger, named "Cairndhu," is shown in Plates 102 and 103, and one of the 1,000-ton hopper-barges in Plate 104; and detailed descriptions of these are given in appendix 1, pages 425–428.

The provision of this powerful dredger was rendered necessary for the expeditious dredging out of Cessnock Dock; and the hopper-barges were required in consequence of the Board of Trade prohibiting the Clyde Trustees from continuing to deposit any harbour and river deposits in Loch Long, and requiring that these should be deposited seaward of Garroch Head, Plate 101; they consented however to the continuance of depositing in Loch Long the new material dredged out of Cessnock Dock. The total quantity of material deposited in Loch Long by the Clyde Trustees up to 18 March 1893, when the harbour and river dredgings ceased to be deposited there, amounted to fully 30,000,000 cubic yards. The total quantity dredged during the year ending 30 June 1894 was 2,310,980 cubic yards, and 6,988 cubic yards were excavated by men, making 2,317,968 cubic yards altogether. Of this total only 54,570 cubic yards were deposited on land, and of the remainder 1,029,245 cubic yards were deposited in Loch Long, 1,231,823 cubic yards in the Firth, three miles S.S.W. of Garroch Head, and 2,330 cubic yards in other parts of the river and Firth, or otherwise disposed of.

The lighting of the channel of the Clyde between Glasgow and Port Glasgow is by three light-towers, at Dalmuir, Rashielee, and Donald's Quay, all above Bowling; by a beacon light at Longhaugh Point, one mile below Bowling; by Dumbuck lighthouse, about two

miles below Bowling; by Garmoyle lightship, one mile below Dumbarton Castle; by Cardross light, one mile above the Clyde Trustees' boundary at Port Glasgow; and by seven lighted buoys on the south side of the channel, between Dumbarton and Port Glasgow; the whole of these lights are lit by Pintsch's gas. The Clyde from Port Glasgow to the sea is lighted by the Clyde Lighthouses Trust, under whose care the estuary is to the Cumbrae Heads, 22 miles below Greenock.

Progress of Glasgow Harbour since June 1887. *Quays.*—The quayage of the harbour, Plate 98, including Kingston Dock and Queen's Dock, and Cessnock Dock so far as in use, is now 7 miles in length, all of which is tidal, with a water area of 185 acres. The extension of the harbour has been from Glasgow Bridge downwards; and until 1865 the sides of the river afforded sufficient room for increasing the quayage, which consisted generally of stone superstructures, founded not much below the then level of low water on bearing and sheet piles, or on planking with sheet piles in front, and for a short length on boulder clay. The piles for the early quays were round home timber from 12 to 15 feet long, giving an available depth in front of the quays at low water of from 5 to 6 feet; and for the later quayage the piles were of sawn red pine, the bearing piles being generally 12 inches square and ranging in length from 20 to 25 feet, and the sheet piling 6 inches thick and from 15 to 17 feet in length.

The rapid lowering of low-water level, due to the deepening of the river from deep water upwards, and the dredging in front of the quays to suit the increasing draught of vessels, brought down a number of the earlier quays, which were generally replaced by timber wharfing. Others of the quays were prevented from falling by longer and stronger sheet-piling being driven in front of the original sheet-piling, and tied back with iron rods, generally to piles driven into the solid ground behind. Later on, the more modern quays had for the same reason to be treated in a similar but more thorough manner: the new sheet-piling was of creosoted pitch pine 12 inches thick and ranging from 30 to 45 feet in length, driven in bays of three and four piles each, which were tied back by iron rods to heavy

blocks of masonry. By this means, notwithstanding the still lowering level of low water, a depth of 18 feet at low water was obtained without injury to the quays.

Docks.—In 1867 the first dock was opened, called Kingston Dock, Plate 98, having 5⅓ acres of water space and 830 lineal yards of quayage. It was substantially wharfed all round, with sheet piling in front 35 feet long by 11 inches thick, and main piles ranging from 42 to 50 feet long by 12 inches square, giving a depth of 10 feet at low water in front of wharf, and 14 feet in centre of dock.

Cylinder Foundations.—The ground in which the quay walls and docks have to be constructed consists chiefly of quicksand and water-bearing gravel. Except in one solitary instance in Queen's Dock, rock is not reached till a depth of from 70 to 80 feet below cope level. In 1870, in order to meet the increasing depth demanded by the ships frequenting the port, and also in order to secure a permanency which quay walls founded on bearing and sheet piles did not afford, the author adopted for the substructure of the walls a single row of brick cylinders, each 12 feet external diameter and 7 feet 4 ins. internal diameter, tongued and grooved into one another, Plate 105. These after being sunk were filled with concrete; and upon them was built a brick superstructure coped with granite, and tied back to blocks of masonry behind by iron tie-rods, 2½ ins. diameter and 65 feet long, placed 24 feet apart. This construction was followed two years later by triple groups of Portland-cement concrete cylinders, 9 feet 7½ inches diameter outside and 5 feet 9½ inches inside, filled with concrete and sand, for the substructure; and for the superstructure concrete rubble, faced with freestone ashlar, and coped with granite. In recent years the freestone ashlar has been succeeded by concrete ashlar made in moulds, and built like ordinary ashlar. The adoption of these cylinders for the substructure has obviated the great expense of constructing coffer-dams and digging trenches to found the walls in, and of heavy pumping; by means of diggers the cylinders were sunk without pumping, and were then filled with concrete.

The single row of brick cylinders with brick superstructure was carried out in the construction of the first 403 yards' length of Plantation Quay, Plate 105. The cylinders were 35 feet 7 inches long, terminating at 2 feet 8½ inches above low water. In order to carry the superstructure, the voids between the tops of the cylinders were lintelled over with cast-iron plates in the front, and with freestone blocks at the back. The remaining length of 297 yards of this quay wall, Plate 106, was carried on groups of triple concrete cylinders, 12 feet diameter outside and 7 feet 4 inches inside, and 29 feet 8½ inches long, with their tops terminating at 3 feet below low water. Chock piles 9 inches square were driven to close up the joints between the successive groups of cylinders; and the voids between the cylinders were lintelled over with cast-iron and freestone lintels. The superstructure consisted of brick facing and concrete rubble backing.

Queen's Dock.—In 1846 an act was obtained for the construction of a dock on the north side of the river, within the precincts of the harbour, Plate 98; but it was not commenced until 1870, in which year an act was obtained for a larger dock than that authorised in 1846. This dock, called the Queen's Dock, has a water area of 33¾ acres, with 20 feet depth at low water; the quayage area is 26⅔ acres, and the quays are 3,334 yards or 1·9 mile in length. It comprises three basins: the north, 1,866 feet long by 270 feet wide; the south, 1,647 feet long by 230 feet wide, with a quay between them 195 feet broad; and an outer basin, 1,000 feet long and 695 feet wide at its widest part. The dock is tidal, and is approached by an entrance 100 feet wide, which is crossed by a swing bridge capable of carrying a rolling load of 60 tons on any part of its roadway.

Concrete cylinders, Plate 109, were adopted for the substructure of all the quay walls of the dock, with the exception of some 800 yards of wall of the usual description, which was founded on concrete blocks laid on boulder clay, Plate 107; and where strong coarse gravel or rock occurred, liquid concrete was substituted for the concrete blocks, by which means all the holes and inequalities in the surface of the gravel and rock were thoroughly filled in. At

two or three places, where pockets of clay were encountered, piling was adopted, Plate 108. Concrete cylinders of a similar description, with occasional variations to suit special circumstances, have been adopted for the 5,213 yards or nearly three miles length of quays constructed in the extension since 1870 of the river quayage, and for the quays of Cessnock Dock, now in course of formation. A description of those used in the construction of Queen's Dock will therefore suffice for all.

Concrete Cylinders.—The cylinders for carrying the quay walls are triple, Plate 109. They were made in rings 2 ft. 6 ins. deep by 1 ft. 11 ins. thick, in movable wooden moulds on a platform. The concrete consisted of five of gravel or broken stones and sharp sand to one of Portland cement of the strongest description, mixed together by steam power in mixers designed for the purpose, water being added to bring the mass into a plastic state. To facilitate lifting, the rings were divided into three and four segments alternately, Fig. 24, so as to break bond when built into the cylinders. The division was effected in a simple manner: malleable-iron dividing plates 3–8ths inch thick were placed radially across the empty wooden moulds in the positions required; the concrete was then filled in, and well punned with hammers weighing 25 lbs., so as to secure homogeneity and a smooth surface. Twelve hours afterwards the dividing plates were withdrawn, and two days later the wooden moulds themselves; and in periods varying from nine days in hot summer weather to three weeks in the rains of winter the rings were ready for removal and building. The volume of one ring complete was $10\frac{1}{2}$ cubic yards, and the weight 18 tons, the heaviest segments weighing about 6 tons each.

The cylinders were each built up of ten rings, each 2 ft. 6 ins. deep, and one ring 1 ft. 6 ins. deep, making with shoe 28 feet total height. The bottom ring, differing from the others, is called a corbelled ring, because it is made less in thickness all round the bottom edge, in order to fit into a cast-iron shoe, Fig. 23, and is tapered inwards and upwards to the full thickness of 1 foot 11 inches. The shoe is 2 feet deep, Plate 110, of 1 inch metal, and

of the same external size and shape as the rings; the under side of the bottom ring rests on a shelf in the shoe, 6 inches below the top edge of the shoe. This shelf is formed by an inner ring of cast-iron, 1 inch thick, projecting at the top 12 inches inwards from the outside of the rim of the shoe, and tapering outwards to the bottom of the shoe, where it joins the outer ring, thus forming a cutting edge to the bottom of the shoe; the wedge-shaped space between the outer and inner ring, Figs. 26 to 29, is filled up with concrete. The shoe is under the outer circumference only of the corbelled ring, the inner part of the ring being unshod. The shoe weighs about $4\frac{1}{2}$ tons, and was made in six parts, Fig. 25, for convenience of placing in the trench, which was excavated along the line of the quay wall. The bottom of the trench was about $4\frac{1}{2}$ feet below low-water level, where it was made 19 feet wide; the sides sloped upwards with a batter of $1\frac{1}{2}$ horizontal to 1 perpendicular, as shown by the dotted lines in Fig. 23. The necessary staging was erected to carry the travelling cranes and digging apparatus. On the bottom of the trench the shoes were placed exactly along the line of the quay wall, and the corbelled ring being placed on the shelf in the shoe was bolted to it by thirteen $1\frac{1}{4}$-inch bolts; a malleable-iron ring, 5 inches broad by $\frac{1}{2}$ inch thick, was sunk into the top surface of the corbelled ring, in which the recess for this plate and the holes for the bolts passing through the ring had been made in the moulding of the concrete ring. The remaining ten rings forming the cylinder were set one on the top of another in Portland cement, in three and four segments alternately, so as to break bond. The cylinders being triple, or in groups of three, were placed in the trench so as to dovetail into one another, one in front and two behind, alternating with two in front and one behind. The sides of the groups where they pressed against each other were flattened for a breadth of 5 feet, so as to ensure a good bearing.

When the building up of the rings forming one group of cylinders was completed to the full height of 28 feet, the sand and gravel were dug out simultaneously from within each of the three cylinders, by means of excavators specially designed for that purpose. From 300 to 400 tons of cast-iron segmental weights of the same shape as

the rings were generally required to force each group of cylinders down to the required depth, which is 50 feet below the cope level of the quay; the tops of the cylinders finish about 3 feet below low-water level. The average rate of sinking was about one foot per hour; in good working sand as much as three feet per hour was attained. When the group had been sunk, each cylinder was cleaned out by means of the excavators to the level of the bottom of the shoe, and was then filled to the top with Portland-cement concrete. On this foundation the quay wall is built. In order effectually to close up the apertures between the adjoining groups of cylinders, a timber chock-pile, 25 feet long by 9 inches square, was driven behind angle-ways, so that a sharp corner bears hard against each of the adjoining cylinders.

The walls are of concrete rubble, and many of the stones weigh from two to three tons each. The walls are faced with freestone ashlar, in courses ranging from 18 to 15 inches thick; the stones are not less than 4 feet long by 2 feet broad on the beds, and the headers not more than 10 feet apart from centre to centre. The cope is of granite, 3½ feet broad by 17 inches thick, in lengths of not less than 4 feet; and the mooring paals or bollards, which are 32 feet apart from centre to centre, are built into the wall immediately behind the cope.

Swing Bridge.—The swing bridge across the entrance to the dock is carried on a foundation probably unique in the annals of swing-bridges, namely on a group of twelve concrete cylinders, Plates 112 to 114, each 9 feet external diameter, 29 feet long and 23 inches thick, resting on cast-iron shoes similar to those used for the quay-wall foundations. The cylinders were sunk in the manner already described; and after they and the interstices between them had been properly cleaned out, all the voids were filled to the top with concrete, chock-piles being driven where required. On the centre of the rectangular foundation thus formed, 36 feet 4 inches long by 27 feet 3 inches broad and 29 feet deep, a stepped ashlar pier was erected, 16 feet square at the bottom, 10 feet square at the top, and 7 feet high, surmounted by a block of granite 7 feet square and 3½ feet deep, on

which the centre lifting-press rests. The pier is surrounded by concrete rubble, the whole forming a mass of masonry 36½ feet long by 32½ feet broad and 10½ feet high up to the level of the floor of the bridge press-chamber. The centre pier sustains a weight of 800 tons. Considerable difficulty was experienced in securing stable foundations for the hydraulic rams for working the bridge, and also for the capstans and the side walls of the bridge pit, in consequence of the ground being loose and insecure where these had to be placed. The difficulty was overcome by using single concrete cylinders placed apart, and spanned between by brick arches, Plate 113. The bridge is 181½ feet long by 40½ feet wide; the length overhanging the centre of centre press is 126½ feet, part of which spans the 100 feet opening. The swing-bridge and hydraulic machinery have been in daily use since 18 September 1877, when the Queen's Dock was formally opened by the admission of the Anchor line s.s. "Victoria," 369½ feet long by 40 feet broad and 2,081 tons register.

On the completion of Queen's Dock, the north and west quays, together 3,155 feet in length by 91⅓ feet and 95 feet in breadth respectively, were equipped with four 19-ton hydraulic fixed cranes for the shipment of coal, and with one 30-cwt. and two 35-cwt. portable hydraulic cranes for the discharge of ore and the loading and discharge of promiscuous cargo. These were subsequently supplemented by eight 5-ton portable steam-cranes, to meet the increasing business. The hydraulic installation, including hydraulic cranes and the swing bridge at the dock entrance, together with the hydraulic machinery for working it, was supplied by Sir W. G. Armstrong and Co. The hydraulic pumping engines have just been much increased in power and efficiency by compounding the high-pressure pumping engine, which has been done by the Glenfield Co., Kilmarnock. The other engine, which was supplied by Sir W. G. Armstrong and Co. about four years after the original installation, was compound from the first. A second accumulator has also been supplied and erected by the Glenfield Co., in a brick tower situated about the centre of the north quay; it is supplied by pipes of 5-inches bore direct from the two pumping engines. The four coaling cranes have also recently

been made much more effective and speedy in their action, by substituting direct-acting rams in place of the hydraulic engines for hoisting and lowering, and by lengthening the jibs so as to command the hatchways of the largest steamers trading with the port. The cranes are now each capable of shipping 25 wagons of coal per hour, each wagon loaded with 15 tons.

Cessnock Dock.—To increase the stability of the quay walls of Cessnock Dock, tie rods $2\frac{1}{2}$ inches diameter and 60 feet long were put in, fixed to blocks of concrete masonry 12 feet long by 6 feet broad and 8 feet deep, Fig. 36, Plate 115. Where a depth of 20 feet at low water is afforded, the tie rods are 64 feet apart; and where there is 25 feet depth at low water, they are 32 feet apart. Where 28 feet depth at low water was desired, the single row of triple cylinders was supplemented behind by a row of twin cylinders, 9 feet $7\frac{1}{2}$ inches diameter outside and 5 feet $9\frac{1}{2}$ inches inside, Plate 116; and the tie rods were increased to $3\frac{1}{2}$ inches diameter and 70 feet length, and placed 64 feet apart.

The total water area of Cessnock Dock when completed will be $34\frac{2}{3}$ acres, the area of quayage $36\frac{2}{3}$ acres, and the length of the quays 3,760 yards or 2·13 miles. The dock will comprise an outer or canting basin, and three branch basins. The general thickness of the superstructure of the walls is 16 feet at bottom, on the top of the cylinders, and $6\frac{1}{2}$ feet at top; but where the substructure contains also a single row of twin cylinders 9 feet $7\frac{1}{2}$ inches diameter, behind the front row of triple cylinders, the thickness at bottom is 26 feet, and at top $6\frac{1}{2}$ feet. The whole of the work is being executed administratively; the iron shoes are supplied on contract, as are also all stones, the dressed granite cope and other granite ready for building, cement, timber, &c. Including tie rods and excavation of trenches, the cost of the walls to give 20 feet depth at low water has been £80 per lineal yard, to give 25 feet £90 per lineal yard, and to give 28 feet depth £120 per lineal yard.

At the annual inspection of the harbour and river on 27th June last, the first instalment of nine hydraulic cranes and the machinery for giving power to them, supplied by Messrs. Fullerton, Hodgart,

and Barclay, of Paisley, were inaugurated. The machinery consists of two separate sets of three single-acting 5-inch pumps, worked by two triple-expansion surface-condensing engines of the most improved design, having cylinders 15 and 22 and 36 inches diameter by 24 inches stroke. The working pressure is 150 lbs. per square inch. The pumps are capable of delivering 200 gallons per minute against a pressure of 750 lbs. per square inch. The engines are fitted with automatic starting gear and high-speed governor and valve. Steam is supplied by two marine boilers, each 11 feet diameter by 10 feet long, with two furnaces in each, 3 feet 2 inches diameter, tested to 300 lbs. per square inch. The boilers are fed by two Cameron pumps, the feed-water being drawn from a large tank under the floor of the engine house, into which the air-pump discharge is led. The accumulator ram is 20 inches diameter with 20 feet stroke. The load case is 12 feet diameter by 20 feet deep, loaded with sand to give a pressure of 750 lbs. per square inch. A safety-valve and regulating gear to the throttle-valve in the steam pipe are provided. Main pressure-pipes of 7 inches diameter, and 8-inch return-water pipes, have been laid from the accumulator to a point in line with the south quay of the north basin; and from there 4-inch pressure and 5-inch return-water pipes branch off, and are led along the south quay in a tunnel constructed in the dock wall. From these pipes branches are taken to hydrant boxes spaced 30 feet apart, in which are stop-valves on branches to the cranes; to the latter branches the cranes are connected by portable flexible piping. A large overhead water-tank is fitted in the boiler house for storing the return water, which is led thence by suction pipes to the pressure pumps. A well has been formed near the north-east corner of the centre basin, connected therewith by a pipe $2\frac{1}{2}$ feet diameter, passing through the dock wall and having a sluice valve inside the well for shutting off the dock water, so as to admit of repairs to the retaining valves and rose boxes. Two 7-inch pipes are led from this well, one to each of the engines, for supplying water for circulating through the condensers. The water is drawn by the circulating pumps, discharged through the condensers, and passes through an 18-inch pipe to a sewer leading by way of Plantation quay into the river. Into this sewer is also led the blow-off pipe from the boilers.

The cranes are capable of lifting 35 cwts. in ordinary working, from 40 feet below cope of quay wall to 25 feet above it, a total lift of 65 feet. The jibs have a range of 29 feet, and project about $27\frac{1}{2}$ feet beyond the face of the quay wall. The cranes are mounted on carriages made of steel plates, and are movable along the whole length of the south quay on rails spaced 14 feet apart. The lifting and slewing speeds are 300 feet and 400 feet per minute respectively. Each crane has two cabins, one on each side of the carriage; and in each cabin is a set of handles for controlling the hoisting and turning motions. The attendant can thus work the crane from whichever cabin is most conveniently situated for the loads to be lifted. At present there are nine of these cranes; but provision has been made in the engine house for power to work thirty-five of this kind, together with five cranes capable of lifting 5 tons each, and five coaling cranes of a capacity of 20 tons each.

With the two engines now fitted there is a large surplus of hydraulic power at present; but when the equipment is gradually extended, as the construction of the dock proceeds, additional power will be necessary; and arrangements have been made in the new buildings for five sets of engines, similar to the two now completed; the seven it is expected will give an ample margin of power to allow of one set of engines being laid off occasionally for overhauling when necessary. The buildings for the hydraulic pumping machinery &c., which are from the design of Messrs. Burnet, Son and Campbell, Glasgow, are of a pleasing appearance, without unnecessary ornamentation, in red pressed brick with red stone facings; they consist of engine and boiler house, chimney 180 feet high, and accumulator tower.

Crane Seat and 130-*ton Crane.*—A description of the recently constructed crane seat and crane, erected on the west quay of Cessnock Dock, and tested to 150 tons, will convey a general idea of their character. As shown in Plates 117 and 118, the external dimensions of the seat are 40 feet square, and it rises 20 feet above the quay level, Fig. 40. The cylinders of the triple groups and twin row behind, which form the substructure of the quay wall, with the

addition of three triple cylinders behind the twin cylinders, together form the substructure of the seat, Fig. 41. All these cylinders are 9 feet 7½ inches diameter outside and 5 feet 9½ inches inside and 49 feet in length; they terminate 7 inches above low-water level of ordinary spring tides, and above them the superstructure rises to a height of 38 feet 10 inches; but while the face of the quay wall has a batter of 1 in 12 from the top of the cylinders, the seat is carried up plumb, Fig. 40. It consists of concrete rubble hearting, faced with concrete ashlar in courses, with granite quoins at each of the four corners, and a granite cope 3 feet thick, with a minimum breadth of 6½ feet on each side and 14 feet at the corners. The total weight of masonry above the concrete cylinders is 4,300 tons.

The framing, shafting, and jib of the crane are of mild steel; the gearing, so far as necessary, of cast steel; and the crane revolves on steel live-rollers working on a steel pathway, Fig. 42, Plate 118. The centre of the crane is a strong massive casting, Plate 119, weighing 9 tons, held down by six steel bolts, each 33 feet 9 inches long and 5 inches diameter, weighing together 8 tons; they are fixed to six washer-plates, each 6 feet square and weighing 13 tons, which are built at equal intervals into the seat at a depth of 30 feet below the top of the seat. A brick-lined tunnel, 2½ feet wide, 11 feet radius at its centre, and 6 feet high, with a manhole, and an approach of same size from one side of the crane seat, Fig. 43, give access to the washer-plates for fixing the cotters in the bottom ends of the bolts. The upward passages for the bolts were formed during the construction of the seat. In the centre casting is placed the steel centre pin, 17 inches diameter, weighing 6 tons, having a forged head, Plate 119. The upper end of the pin carries a steel clip, having on its under surface a steel pathway, between which and a similar pathway fixed in the revolving frame of the crane move sixteen live rollers, Plate 120, for reducing the friction to a minimum. The diameter of the main-roller path, bolted down on the top surface of the seat, is 33 feet, Fig. 42, Plate 118, and its weight 12 tons; in the live-roller ring there are seventy-five cast-steel rollers, of a maximum diameter of 14 inches, weighing in all 10½ tons.

The framing is 27 feet in height, and weighs 50 tons. The boiler is 14 feet high by 6 feet diameter, and weighs 6 tons. The jib is composed of two tubes, each 3 feet 3 inches diameter at the centre, well braced together. It is 90 feet long, and weighs 45 tons, including stays; its extreme height above cope level of quay is 110 feet. The centre of the jib-head pulleys for heavy loads, which are 5 feet 3 inches diameter, is 100 feet above cope level of quay wall; and the light-load pulleys of 2 feet 6 inches diameter are 107 feet 6 inches above cope level. The single tension-rods are 10 inches by $2\frac{3}{4}$ inches, and the double tension-rods 10 inches by $1\frac{1}{2}$ inch, and the diameter of the pins 8 inches, the whole weighing 15 tons. The diameter of the hoisting drum is 5 feet 2 inches, its length 10 feet, and its weight $10\frac{1}{2}$ tons. The gearing weighs 8 tons; the castings are in all 120 tons; and the crane in working order, exclusive of back balance, is 270 tons. In the ballast box for balancing are 100 tons of iron and steel punchings.

The margins allowed for safety in the various parts of the crane are:—in the main framing, jib, tension rods &c., six to one; in the wire ropes, eight to one; and in the centre holding-down bolts, in order to provide amply for deterioration by rust, twelve to one. The crane has two speeds for heavy lifts, 130 and 60 tons and an empty block lift; and two for light lifts, 20 and 8 tons. The engine for the heavy lifts has two cylinders, each 12 inches diameter and 16 inches stroke; the engine for light lifts has two cylinders, each 8 inches diameter and 12 inches stroke. There are two speeds for revolving, and the turning engine has two cylinders, each 8 inches diameter and 12 inches stroke. Plough steel-wire ropes, made by Messrs. Thomas and William Smith, Newcastle, are used for lifting and lowering. The heavy lifts are taken on eight ropes of $2\frac{1}{8}$ inches diameter, composed of six strands of steel round one strand of manilla; each strand is composed of thirty-seven wires, 0·101 inch diameter, and the average tensile strength per wire is 1,600 lbs. The light lifts are taken on a double rope of $1\frac{1}{2}$ inch diameter, composed of six strands, each of thirty-seven wires of 0·072 inch diameter, round one centre strand of manilla; the average tensile

strength per wire is 1,080 lbs. The gin block for heavy lifts has four pulleys, each 5 feet 3 inches diameter; it measures 12 feet by 7 feet by 3 feet, and weighs about 7 tons. The radius of sweep for the heavy lifts is 65 feet, or 45 feet beyond the face of the seat; and for the light lifts 71 feet, or 51 feet beyond face of seat.

The lifting speed for 130 tons is 4 feet per minute, 60 tons 8 feet, 20 tons 12 feet, 8 tons 30 feet, and empty block 32 feet per minute. The revolving speed with 130 tons is one revolution in five minutes; and with 60 tons and under, one revolution in two and a half minutes. To prevent the possibility of overloading at any time, the crane is provided with a Duckham's 160-ton hydrostatic weighing machine.

This crane was constructed and erected by Messrs. Cowans, Sheldon and Co., Carlisle, and is practically a duplicate of a crane made and erected by them on Finnieston Quay in 1893.

Throughout the harbour and docks berths are set aside for special trades, such as coal, lime, timber, river passenger steamers, and cattle; and more than half the total quayage of seven miles is occupied by the leading lines of steamers trading to outports of Scotland, England, and Ireland, to the leading ports of Europe, to the British Colonies, and to America, Canada, the East and West Indies, Africa, &c.

The riverside and dock quays are well equipped with everything necessary for the speedy loading and unloading of vessels, including 6½ miles of harbour railway on each side of the harbour, connecting with the public railways. The Clyde Trustees have no warehouses, but have nearly 33 acres of floor space in sheds for the accommodation and protection of goods. The sheds most recently erected are those in Cessnock Dock; they cover 22,607 square yards of quay, and are two storeys high, equipped with apparatus for lowering general cargo into carts and railway wagons at the back outside, and with shoots for loading bags of flour into carts inside. Unlike dock companies, the Trustees do not load and unload goods; this work with its attendant profits is left to the shipowners to perform. Those who have allocated berths are allowed to place steam cranes on the breasts of the quays; and there are at present thirty-two of these in use, ranging from

30 cwts. to 30 tons lifting power. By means of fifty-five steam and hydraulic cranes, ranging from 30 cwts. to 130 tons lifting power, the Trustees load coals and heavy machinery, discharge ore, mast vessels, and place boilers and engines on board steamers built on the river banks and in the neighbourhood; and their four most powerful cranes rest on concrete cylinders similar to those described for the quay walls.

Graving Docks.—The first public graving dock in Glasgow harbour was opened in 1875, and is 555 feet long, with 22 feet 10 inches on the sill at high water of spring tides; it was constructed by the Clyde Trustees at a cost of £134,800, exclusive of land. A second, opened in 1886, 575 feet long by 52 feet 4 inches wide at bottom and 92 feet wide at top, with the same depth of water on the sill, was constructed alongside the first, by the author and from his designs, without the aid of contractors, as has been the case with all the quayage of the harbour for the last twelve years; the cost was £108,200, exclusive of land. A detailed description of this graving dock is given in appendix 2, pages 429–34. A dock of similar construction as regards material is now being built administratively like Cessnock Dock and under the same staff, alongside the second dock; its dimensions are 880 feet length, 81 feet 8 inches width at bottom and 115 feet at top, with 26 feet 6 inches depth on sill at high water of spring tides.

Ferries.—Ten cross-harbour passenger ferry-steamers provide an ample day and night service for four ferries within the limits of the harbour and two ferries at Govan and Whiteinch; while two vehicular and passenger ferries combined—at Finnieston, about the centre of the harbour, and at Govan, its western boundary—afford every facility for cart and carriage traffic.

The vehicular ferry steamer at Finnieston, designed and built by Messrs. William Simons and Co., Renfrew, commenced plying five years ago. Its novel feature is an elevating deck, raised and lowered by bevel and worm gearing, so that at any state of the tide the deck is brought to the same level as the quay. The hull is built of steel,

with iron decking divided by thirteen bulkheads, five of which are transverse; it is 80 feet long by 44 feet broad, and 12 feet deep amidships, while the maximum draft when loaded is $9\frac{1}{2}$ feet. The vessel is propelled by four screws, two at each end, in order to give it great manœuvring power.

The elevating deck is 78 feet long by 32 feet broad; 19 feet of the width is for vehicles, and $6\frac{1}{2}$ feet on each side for passengers. It is carried, lifted, and lowered by three vertical screws on each side, of forged steel 7 inches diameter; these are supported by six columns formed of two box-girders, 12 by 14 inches, of channel section, which are placed 2 feet apart, one on each side of each screw. Each of the screws works in a manganese-bronze casing, which is bolted between the two box-girders that form each column, and is placed so that the deck may rise 14 feet. The columns are held in position at top by longitudinal and transverse steel girders of I section, and by girders of the same section fixed to the sides of the vessel; and on the top longitudinal and transverse girders is placed the wheelhouse, with handwheel to the steam steering gear on deck. The engines for propelling the vessel and for working the elevating deck are three horizontal triple-expansion, all of the same design and size, having cylinders 9 and $14\frac{1}{2}$ and 24 inches diameter with 18 inches stroke. All three are placed in one compartment in the centre of the hull. Two are placed athwartship, one of them driving the line of shafting that runs fore and aft and works the port screws at both ends of vessel, while the other drives the shafting for the starboard screws. The third engine is placed between the other two, with pistons working fore and aft, driving a line of shafting which runs athwartship, and is connected by spur and bevel wheels with two lines of fore and aft shafting on either side of the vessel; these are geared to each of the vertical screws for moving the elevating deck.

The vessel accommodates three hundred passengers and eight loaded carts with horses; or seven hundred passengers alone. It plies across the river between a recess on the north side and two dolphins on the south side; and has proved a perfect success in every way.

The Trustees have also a row-boat passenger ferry across the mouth of the Kelvin at its junction with the Clyde at Govan Ferry. The Renfrew Burgh authorities maintain a steam vehicular ferry across the river at Renfrew, and Lord Blantyre one at Erskine. The number of passengers conveyed across the river at the different ferries belonging to the Trustees for the year ending 30th June 1894 was 8,849,220, and of vehicles 233,167; and the gross revenue derived therefrom amounted to £18,735 3*s.* 4*d.* The charge for crossing is one halfpenny for each passenger; but eighteen single-journey tickets are sold for sixpence.

In April 1884 the Clyde Trustees established a service of harbour passenger steamers, each called "Clutha"—the Gaelic name of the Clyde—to ply between Victoria Bridge, Glasgow, and Whiteinch, a distance of 3½ miles. These steamers, now ten in number, are twin-screw, 74 to 102 feet long by 13 to 17 feet beam, carrying from 235 to 360 passengers. They ply at ten minutes' intervals, at the fare of one penny for the whole distance; and call at various intermediate stations on both sides of the harbour. During the year ending 30th June 1894 they carried 3,376,425 passengers with a gross revenue of £14,068 8*s.* 9*d.*

APPENDIX 1.

NEW DREDGING PLANT.

The new Dredging Plant consists of a single-ladder twin-screw dredger, 200 feet long by 37 feet broad by $12\frac{1}{2}$ feet deep, having a mean draft of 8 feet, capable of dredging at the rate of 600 tons per hour in 40 feet depth of water, and of cutting its own flotation; and two twin-screw hopper-barges of 1,000 tons capacity, each 200 feet in length by 34 feet in breadth moulded, and $15\frac{1}{2}$ feet deep, having a speed of ten knots per hour when loaded, and a mean draft of $12\frac{1}{2}$ feet. All three vessels were constructed in 1892 by Messrs. Fleming and Ferguson, Paisley, from drawings and specifications prepared by the author. The plating of the hulls of both dredger and barges is of steel; and steel has been used wherever it could with advantage be applied.

Dredger.—Plates 102 and 103. The hull is subdivided into eight water-tight compartments by means of iron bulkheads. The decks are of pitch pine. Steam and hand steering gear are provided. The dredging and propelling are performed, the latter at a maximum speed of 6 miles per hour, by a pair of compound inverted direct-acting surface-condensing engines, capable of indicating 750 horse-power with a working pressure of 80 lbs. per square inch above atmosphere; the cylinders are 26 inches and 51 inches diameter, with a stroke of 36 inches. The propellers are of steel; and are protected by strong iron guards, supported and stayed from the vessel's counter. The boilers, two in number, each have two furnaces, 3 feet 3 inches diameter, giving a heating surface collectively of fully 2,000 square feet; they are multitubular, 10 feet long by 11 feet 8 inches diameter, of mild steel, and according to Board of Trade requirements; the water is heated before admission by a Rayner feed-water heater.

The main framing for carrying the upper tumbler, ladder, and traversing gear, is of iron plating, of box form with outside angles

and of ample strength, securely connected to the hull by specially prepared seating, and by brackets to the sides of the well and to the keelsons. The sheers for carrying the lower end of the bucket ladder are also of box form, well trussed in the direction on the strain, and firmly secured to keelsons, deck-beams, &c. The upper and lower tumblers are of cast-steel; the upper is five-sided and the lower seven-sided. The buckets, thirty-five in number, each of 22 cubic feet capacity, are constructed entirely of steel, with hard steel wearing-plates. The intermediate links and link pins are of best forged scrap-iron; the pins are steeled on the working side and hardened. The bucket ladder is built in the best style of girder work, with all butts and edges of plates planed; it is formed of two parallel plate-girders, bound together at top and bottom by cross ties of box section, with eleven intermediate plate-ties. There are two shoots on each side of the dredger for loading barges, placed to suit the forward and aft positions of the bucket ladder; all four shoots are worked by a pair of horizontal engines in a house on the deck. The traversing carriage on the main framing is worked by an independent vertical engine and gearing; it travels sufficiently far aft, which will be its usual position in working, to admit of the ladder and lower tumbler, with all the buckets in position, being hoisted on deck for inspection and repairs.

All spur and bevel pinions and mitre wheels in connection with the main and hoisting gearing are of cast-steel, while the large wheels are made of a special mixture of cast-iron and steel. The dredging machinery is adapted by steel change-wheels to drive the buckets at speeds of 12 and 18 per minute without altering the speed of the engines from 60 revolutions; while by varying the speed of the engines any intermediate speed of buckets between 12 and 20 per minute can be obtained, when dredging to a depth of 40 feet below the surface of the water, with the ladder set at an angle of 45 degrees. Provision is made by adjustable friction-gear, fitted to the top-tumbler wheel, to relieve the machinery of any sudden strain which might otherwise be brought upon it by the buckets meeting with obstructions, such as boulders, sunken wrecks, lost anchors, &c. Powerful steam mooring winches are fitted, two at the

bow and one at the stern. The maximum speed of the former is 50 feet per minute in working ahead on the bow-anchor chains; and the maximum speed for side chains or ropes is 60 feet per minute. The maximum speed of the stern winch, for taking in anchor chains, is 90 feet per minute; and the maximum speed for side chains or ropes is 120 feet per minute. The backing speed in both bow and stern winches is 90 feet per minute. The hoisting of the bucket ladder, which can be done at any speed up to 13 feet per minute, is performed by a pair of horizontal engines, with 14-inch cylinders and 16 inches stroke; and the lowering is done by a powerful brake handled on the deck. The hoisting purchase consists of four upper and five lower brass-bushed wrought-iron sheave-blocks. The hoisting chains are $1\frac{3}{8}$-inch diameter, of crane-chain quality, short linked, tested to Admiralty strain, and wound on a spiral-grooved cast-iron barrel, 10 feet long and 7 feet diameter, large enough to take the whole chain on it without riding. A 10-ton steam derrick crane is placed on deck, so as to command the bottom tumbler, and to place it on a barge or punt, or on a quay. The dredger is lighted throughout by electricity, with incandescent lights on deck and below, and three arc-lights of 2,000 candle-power each; the latter are suspended in triangular form 6 feet apart, from an iron post with a cross-tree, placed on the top of the main framing, in compliance with the rule for the lighting of dredgers moored in the harbour of Glasgow and in the river Clyde.

Barges.—As shown in Plate 104, the barges have each a raised fore-castle, a main steering bridge and wheel house, a flying steering bridge, and a gangway extending from the fore end of the hopper to the main bridge. The hulls of each are subdivided into six water-tight compartments by bulkheads carried up to the main deck; and there is a water-ballast space on each side of the length of the hopper, 8 feet high from the bottom plating, with a water-tight deck, each space being divided into two compartments by a transverse bulkhead, with pipe connections for filling and emptying each of the four compartments.

The hopper is 72 feet long by 27 feet wide at deck line, and 11 feet wide at bottom, with a depth of 15 feet to deck line. It is divided into two equal compartments by a partial bulkhead, carried up to support the curved box-girder in which are fixed the pulleys for working the hopper-door chains. The hopper doors are of elm, twelve in number, hinged to the bottom of the hopper sides, and closing against a fore-and-aft box-keelson, $3\frac{1}{2}$ feet high by 2 feet wide. For protecting the hopper sides against damage by stones falling heavily upon them, $\frac{3}{8}$-inch malleable-iron plates, 4 feet wide, are hung from the deck beams along both sides of the hopper.

The barges are each propelled by two triple-expansion engines of 1,200 I.H.P. collectively, each driving its own propeller; the cylinders are 15 and 24 and 37 inches diameter, with a stroke of 24 inches. Each engine is fitted with independent steam starting-gear, so that one man can handle both engines with ease. Steam is supplied at 150 lbs. per square inch by two return multitubular boilers, each 12 feet diameter by 10 feet long, with Purves' corrugated furnaces 3 feet 6 inches diameter; the water is heated before admission to the boilers, as in the dredger. The propellers are 9 feet diameter, having four steel blades bolted on; and the shafting is 8 inches diameter. The vessels are steered by Messrs. Alley and MacLellan's steam steering-apparatus, which can be worked from either of the bridges. In the wheel house is one of Sir William Thomson's compasses, and on the flying bridge an ordinary compass. Messrs. France and Morgan's reply telegraphs are fitted on both bridges, communicating with each engine in the engine-room.

There are two sets of powerful three-barrelled winches on deck, one set immediately forward and the other immediately aft of the hopper, for manipulating the hopper doors; each set is worked by a two-cylinder horizontal engine, while they are so designed as also to be worked by hand. One of Messrs. Clarke, Chapman and Co.'s steam windlasses is fitted on the fore-castle for working the anchor chain and mooring ropes; and a steam capstan by Messrs. Alley and MacLellan is placed at the stern for mooring.

APPENDIX 2.

No. 2 Graving Dock.

The following are the principal dimensions of this dock, which was opened on 13th October 1886:—

	Feet.	Ins.
Length of floor from inside of caisson . .	575	0
Width at bottom	52	4
Width at top	92	0
Width of entrance at bottom . . .	57	6
Width of entrance at top	67	0
Depth of water on centre of sill at average high water of ordinary spring tides .	22	10

The wing walls and apron of the entrance are carried on triple concrete cylinders 9 feet diameter outside and 5 feet 9 inches inside, sunk 24 feet into the ground, and filled with concrete, their tops being 3 feet below the level of top of sill at centre. One of the triple cylinders was used as a well for the main temporary 13-inch centrifugal pump by Messrs. Easton and Anderson, which was required to keep under the heavy influx of water that was met with in the gravel into which the excavation for the dock had to be carried. Into this well were led three lines of 9-inch open-jointed spigot-and-faucet pipes, made of cast-iron under the sills, and of fire-clay thence to the upper end of the dock. These pipes were laid under the foundations of the floor on an inclination of about 1 in 300, with branches to each side as required, in order to give free passage to every spring of water that was met with. In order to prevent these lines of pipes from choking with sand, a small wire-rope with wire brush attached was carried through each from the well right on to the upper end, as the work of excavation proceeded from the entrance to the head of dock; these brushes were quite successful in keeping the pipes clear. The pipes were bedded in clean riddled gravel to the depth of 18 inches, whereby the ground

was kept well dried for laying the bottom bed of concrete forming the lowest section of the foundations of the floor and side walls. On this concrete bed, which is 12 inches thick at the centre and 3 feet 2 inches at the sides, an invert of brick in cement, 4 feet 2 inches thick, was laid to the radius of 120 feet, surmounted by a bed of concrete 4 feet 5 inches thick in the centre, tailing out to 12 inches on each side, with a camber of 6 inches on the upper surface. On this is laid the flooring of the dock, consisting of nidged granite causeway 6 inches thick, set in and grouted with cement. The floor at the centre is 12 inches below the sill, and is level longitudinally.

The limited width of the site of the dock prevented the excavation from being taken out to the usual width on the top. This, with the desire to get the dock as long as the ground would admit of, necessitated driving along both sides and round the head pitch-pine sheet-piling 28 feet long, in four-pile bays with slip tongues; 16 feet of the length was driven into the undisturbed bottom, and the piling is 9 inches thick along the sides, and 12 inches thick round the head. In front of the sheet-piling, brickwork was carried up from the invert to above the top of the piling; and the ground behind the piling was cut away for a breadth of 7 feet 6 inches and a depth of 6 feet, and filled up with concrete, on which were built the outer side walls, 37 inches thick at bottom and 18 inches at top, plumb at back and stepped on the inside, the whole being carefully pointed outside to secure water-tightness. Inside the walls the whole body of the dock is of concrete, except the side walls of the entrance, the stairs, timber slides, top altar course, and cope, which are of granite; all the other altar courses, seventeen in number, are of granolithic, 14 inches on the tread and 18½ inches rise, except the bottom course, which has 30 inches average rise. The concrete of the sides was put in between movable frames roughly stepped to receive the granolithic altar courses, which were moulded on a platform on the working ground, and when thoroughly dry were built in position like ashlar: except the bottom altar course, which was made *in sitû* in 8 feet lengths and in alternate blocks, to allow of setting and shrinkage.

The floor of the caisson chamber is an invert of brick in cement, with granite stones and cast-iron blocks alternately for carrying the rails for the caisson to travel on, the cast-iron blocks being cored out for the drainage of the mud from the rails. The sides and end walls of the chamber are of brick, with rectangular voids filled with concrete, and having a freestone string-course on each side for the hauling-chain path. The caisson chamber is covered over with Lindsay's steel-trough decking, having the troughs filled up with concrete and a layer 4 inches thick over the whole, which is causewayed over to form a part of the roadway.

The semicircular head of the dock is formed of brick in cement, stepped at back, with rectangular voids filled with concrete, and faced with moulded granolithic-faced concrete ashlar, battered on the face to 1 inch per foot in courses of 18 inches deep, chamfered on top and bottom edges; the stretchers are 4 feet long by 1 foot 9 inches broad on bed, and the headers 3 feet 6 inches long by 2 feet broad. On each side of the dock there are four timber slides, and two stairs, with two stair approaches to each. The stairs are 4 feet 6 inches wide, with landings about half way down. Each landing is approached from the surface by two stairs parallel with the dock, and entering from opposite directions; the steps of the stairs are 12 inches broad and 6½ inches rise.

The caisson for closing the entrance is of iron, rectangular in shape, as first used in 1850 to close the lock entrance at Keyham, with folding roadway, and handrails, similar to the caisson with folding handrails and lowering and raising roadway deck, which was adopted in 1867 by Sir Andrew Clarke to close the entrance to the Royal Somerset graving dock, Malta; but instead of sliding, as at Malta, it is moved on rollers fixed under it, which run upon broad iron rails, laid on each side of the floor of the chamber and berth, as successfully applied by Mr. Kinipple in 1873 at Garvel graving dock, Greenock. The caisson has a water-tight deck about half way between bottom and top, and is ballasted with 180 tons of concrete ballast, 60 tons of which is portable, being in 12-inch cubes; these can be lifted out for enabling the caisson to be floated out of its recess if required.

The whole of the cement used in the construction of the dock was the best quality of Portland. The proportions of gravel and broken stones to cement for the concrete were as follows:—for the triple cylinders, 5 to 1; floor and sides of dock and ballasting of caisson, 6 to 1, the concrete on the sides being supplemented by a plentiful supply of rubble; covering of the caisson chamber, 8 to 1; and filling of the concrete cylinders, 9 to 1. The gravel for the concrete was mostly got from the excavations, and the remainder was Thames gravel brought round from London as ballast; a considerable quantity of the rubble stones were got from the blasting of Elderslie rock in the river above Renfrew. All the concrete was mixed by Jamieson's mixers, and the stones were broken by Hope's stone-breaker. The granolithic altars consist of three of crushed granite to one of cement; and the granolithic-faced ashlar blocks are faced with 6 inches of granolithic of the same quality, the remainder of the block being 5 to 1 concrete. The mortar for building the brickwork was composed of 1 of cement to $2\frac{1}{2}$ of sharp sand; and for pointing, 1 of cement to 1 of sand. All the sand was obtained from the excavations for the dock.

The dock is emptied by the pumping engines of No. 1 dock through a cast-iron pipe 5 feet 9 inches bore; but this pipe having been put in simultaneously with the construction of No. 1 dock when the second dock was intended to be 2 feet 10 inches less in depth than it actually is, the last few inches of water above the floor in No. 2 dock have to be emptied by a 10-inch auxiliary centrifugal pump by Messrs. Easton and Anderson, which is driven by a 16-H.P. gas engine by Messrs. Crossley Brothers, Manchester. The caisson was made by Messrs. Hanna, Donald and Wilson, Paisley; the caisson hydraulic hauling engine, which can also be worked by hand, is by Messrs. Tannett, Walker and Co., Leeds; and a new hydraulic pumping engine, for supplying the accumulator for the hydraulic power to work the hauling engine of No. 2 dock and the capstans and sluice valves of both docks, has been supplied by Messrs. Fullerton, Hodgart and Barclay, Paisley. The sluices were furnished by Messrs. Easton and Anderson. All the three engines are underground, in roomy white-glazed brick-lined houses, two of

which are roofed over at the surface with rolled beams and concrete and Gourlay's prismatic lenses for lighting.

The strata which had to be excavated for the dock consisted of about equal proportions of soft clay, sand, and gravel. The excavations amounted to 188,943 cubic yards, of which—

148,167	cubic	yards	were deposited in Loch Long.
11,505	,,	,,	gravel used for concrete.
22,686	,,	,,	sand sold.

There were built in the construction of the dock—

21,000	cubic	yards	of	concrete.
1,700	,,	,,		rubble concrete.
19,000	,,	,,		brickwork.
12,000	cubic	feet	of	freestone ashlar.
31,000	,,	,,		granite ashlar.
4,800	,,	,,		concrete ashlar.

3,000 square yards of granite-nidged causeway 6 inches thick.
16,000 linear feet or 3·03 miles of granolithic altar courses.

The act for the dock was passed on 7th July 1873. Ground was broken for its construction on 2nd August 1882. Pumping was commenced on 1st June 1883. The sinking of the first concrete cylinder was commenced on 21st December 1883. The concrete foundation of the dock entrance and caisson chamber was commenced on 26th May 1884, and the first brick was laid on 29th May. The last cope-stone was laid on 27th March 1886. The pumping ceased and the dock was ready for opening on 30th August 1886; the delay of the opening till 13th October was consequent on the removal of the cofferdam across the entrance, and the completion of the dredging of the entrance.

The number of men employed on the work varied from 100 to 300; no loss of life or limb occurred during the execution of the work. The plant employed consisted of:—one locomotive; two portable pumping engines; one 12-inch and one 13-inch centrifugal pump; one portable engine, working a stone breaker and a concrete mixer; one portable engine working a concrete mixer; two Jamieson's concrete mixers; one Hope's stone breaker; two 10-ton

steam overhead travelling cranes; one hauling engine; one 10-ton, four 5-ton, and one 3-ton steam derrick cranes; three 3-ton hand derrick cranes; forty 3-yard wagons; 40-lbs. to 75-lbs. steel rails, &c.

The parliamentary plans were prepared and carried through parliament by the author, who also prepared the working drawings and constructed the dock without the aid of contractors.

The President said the author had given the Institution a paper on a large and important piece of work which he had most successfully carried out. Its interest was perhaps not so exciting as that of some recent papers on similar work which had caused much trouble by failures; but it was at least as instructive, and certainly much more pleasing to its author. In this paper Mr. Deas had done something which was always most acceptable to engineers: he had given a mass of details, both important and interesting, but seldom made public in regard to work of this kind. Although the paper was not discussed, he was sure the Members would join in giving Mr. Deas a most hearty vote of thanks for the elaborate and complete way in which he had placed before them the results of his long experience.

Mr. Deas said he had not expected that the paper would lead to any discussion. Having been a mechanical engineer before he became a civil engineer, he realised how largely the work which had been carried out on the Clyde during the last twenty-five years had been indebted to mechanical engineers for the facilities they had afforded, especially in regard to the mode of sinking cylinders by the diggers, which had been so successfully applied not only to cylinder sinking on the Clyde but in other works of the same kind. The novelty connected with the works of the Queen's Dock and the Cessnock Dock was to a considerable extent due to the adoption of concrete cylinders instead of iron. Iron cylinders were much too costly for the substructure of quay walls; and his attention had therefore been directed first to brick cylinders, which were found successful. Afterwards he had decided to go a step further and use concrete, which had been equally successful. Upwards of three miles of the quay walls of Glasgow Harbour had been founded on concrete cylinders; and the maintenance of these since they were constructed had not cost the Clyde Trustees £100. Even in the brick walls not a brick had required to be put in for repairs.

NOTES ON MODERN STEEL-WORKS MACHINERY.

By Mr. JAMES RILEY, of Glasgow.

Amongst the many results of the introduction of Mild Steel into engineering work may be mentioned the development of the various mechanical appliances used in the process of manufacture of that metal into the finished forms of sectional bars, plates, &c. As engineers have become better acquainted with its many excellent qualities, and have realised the possibilities opened up by its use, their demands on manufacturers have steadily increased for plates and bars of greater area, strength, and weight. Conversely, manufacturers have stimulated these demands by costly outlay on improved machinery, designed to deal with masses and weights which but a few years ago would have been looked upon as unattainable. This continuous emulation has resulted in the massive installations of Machinery to be found in the most modern Steel Works. In this paper the object of the author is in a few concise notes to draw the attention of the Institution to the chief advances which have been made in recent years in the machinery used in large steel works in this country, and principally in Scotland.

Rolling-Mill Engines.—The improvements or modifications which have been made of late in rolling-mill engines have been in the direction of largely increased strength and power, and of careful attention to the designing of details: these latter perhaps small in themselves, but in the aggregate having an important bearing on the economical working of the engines, and on the diminution of the cost of maintenance. In these days of keen competition, when rigid economy is essential in order to reduce costs to a minimum, it is important that the consumption of steam should be reduced to the

lowest possible; hence for pull-over or non-reversing mills compound condensing engines have been introduced with automatic valve-gear, which are working with a consumption of not more than 3 lbs. of fuel per I.H.P. per hour, in place of the old wasteful engines which consumed from two to even four times that quantity. With reversing-mill engines also attention has been turned to the economising of steam, and trials have been made with compound engines. Compound reversing engines have not proved economical, when applied to mills —such as cogging or roughing mills—where the pieces being rolled are of short length and necessitate frequent reversals; while their use has been accompanied with troubles and difficulties in other directions, which have more than counterbalanced the small economies possible. Where water is available in sufficient quantity, it has been utilized in condensers, connected either with single engines, or with several engines from which the exhaust steam is led to the condensers at a central station. The use of central condensing stations for a number of engines appears to have received more attention on the Continent than in this country; it is stated that recently this plan has been adopted there in several instances, and with satisfactory results both in economy and otherwise. The only instance known to the author where the plan has been adopted on a large scale in this country is at the North Eastern Steel Works at Middlesbrough, where a central condensing and pumping station of considerable magnitude has been put up by Mr. Cooper; and although no definite statement has yet been made as to results, they are believed to be not unsatisfactory.

Rolling Mills.—The consideration of rolling mills will here be limited to those engaged in the production of plates; and cogging mills are naturally the first to be dealt with.

Cogging Mills.—In the earlier days steel slabs to be rolled into plates were made from ingots under the hammer. Labour difficulties and possible economies led the author early in 1884 to put down at Blochairn Works the first cogging mill used for this purpose. Recent slab-cogging mills are in all essential features like that pioneer mill,

2 Q

but are much larger and stronger, and therefore are capable of dealing with heavier ingots, yielding much larger and heavier slabs. Modifications have also been made in the machinery for tilting up the ingots and slabs for alternate edge and flat rolling.

In Plates 121 and 122 is shown a good example of a slab-cogging mill recently made by Messrs. Lamberton and Co. for the Wishaw Steel Works. The rolls R are 8 feet 6 inches long and 40 inches diameter, and at both ends have grooves in which slabs 54 inches wide can be rolled on edge. The housings H for both rolls and pinions are massive, and well fitted for their work. The pinions of cast steel are 48 inches diameter, and have helical teeth 36 inches long, with shrouds or flanges at the ends. The spindles are of steel; the upper has spherical ends, and is supported from the pinion housing at one end and from the top-roll chock at the other. The mill is fitted with screwing-down gear G, driven through gearing by a pair of steam engines; and an indicator is fitted to guide the screwer. Live rollers L of steel are fitted back and front of the rolls, and are driven by a steam engine E with cylinders 9 inches diameter by 15 inches stroke, through gearing in the ratio of three to one. In front of the mill is a set of tilting machinery, which is illustrated in Plate 123. The turning levers T are placed on movable carriages, which traverse to and fro across the front of the rolls as required, being actuated by hydraulic power. Thus the ingot or slab can not only be turned from flat to edge or vice versâ, but can also be traversed from one end of the rolls to the other. The cradle, Plates 124 and 125, for receiving the ingot and lowering it upon the feed rollers, is of massive character, being designed to deal with ingots up to 10 tons in weight. It is controlled by hydraulic power acting through a ram, which carries a sliding block B taking on to the pin of a crank fitted on the axle of the cradle C. The mill is driven by a pair of massive engines having cylinders 46 inches diameter by 60 inches stroke, and gearing in the ratio of $1\frac{3}{4}$ to 1.

In Plate 126 a different kind of cogging mill is shown. It was designed in 1890 to meet some special requirements at the Blochairn Steel Works, and to embody some modifications suggested by the author's experience with the ordinary cogging-mill. Up to

that time the widest slabs made in cogging mills did not exceed 36 inches. Slabs of much greater width were then required under special circumstances; and it was decided to adapt the mill to produce them up to 60 inches wide. It was also decided not to turn them up on edge: thus dispensing with the necessity for the powerful and somewhat cumbrous as well as expensive tilting-gear which would have been required for such wide slabs. Furthermore experience had shown that in the course of years the cost of maintenance of the live-roller gearing was considerable; and it was decided to dispense with this, and to adopt other methods of moving the ingots and slabs to and from the mill. These considerations led to the mill being made of the "universal" kind, with one pair of horizontal rolls for work on the flat, and one pair of vertical rolls for work on the edge of the slabs. Every part of this mill is made of steel. The housings are massive, and are fine examples of the steel-founder's art. Besides the usual provisions connected with horizontal rolls, the housings have also provision for the footsteps and bearings of the vertical rolls, as well as for the strong horizontal shaft by which the latter are driven. Furthermore one of the vertical rolls is made to move forwards and backwards across the mill, so as to put work on the edges of the slabs; and has a traversing motion through 28 inches, so that slabs can be made of any width from 60 inches down to 32 inches. With these arrangements it was contemplated that armour plates up to nearly 5 feet wide might be rolled in this mill, with their edges so well finished that comparatively little machine-work would be required upon them. With a view to the transverse motion of the vertical roll, provision was made in the housings for the necessary screws and nuts by which it is effected, as well as for the slides and guides necessary for keeping the roll in the true vertical plane. Hence it will be seen that, in order to meet these requirements as well as some other details, the production of these housings was a work involving no little skill and anxiety.

Screwing-down gear G for the horizontal rolls is placed in the usual way on the top of the housings. On the housing and side frame of the mill is arranged screwing gear for setting up the vertical roll transversely, and simultaneously for setting up the necessary

guides for the slabs, these guides extending a considerable distance in front and at the back of the rolls. Both sets of gear are driven by a small pair of engines through gearing. They can be worked together; but the practice is not to work them simultaneously, but alternately as required, so that work can be put on the flat or edge of the slab at choice. To this end clutches are arranged on the shaft of the small driving engines.

The horizontal rolls R are 28 inches diameter, and the vertical rolls V about 21 inches. The latter are driven by bevel wheels on a horizontal shaft F, which extends to the pinion housings H and receives its motion through a pair of wheels, one on its extreme end which works into another keyed on the shaft of one of the mill pinions. This outer end of the driving shaft is carried in bearings formed in the pinion housings. As one of the vertical rolls has a traversing motion, the bevel wheel driving it must necessarily slide along the shaft. In order to keep it in gear with the crown wheel on the roll, a special form of yoke and thrust bearing was designed, which is carried on the projecting end of the vertical roll above the crown wheel. The driving wheel on the horizontal shaft F has a long boss or sleeve, on which are formed collars; these fit into and run in the thrust bearing on the top end of the vertical roll. The spindles for driving the horizontal rolls are both supported in bearings, the upper one in a manner similar to that already described for the cogging mill at Wishaw.

At the front and back of the rolls are dead rollers, carried in brass bearings on side frames, and extending a considerable distance from the rolls. At each extremity are special carriages A and B, similar though not identical in design, A for bringing the ingot to the mill at one end, and B for removing the slab to the shears S at the other. These carriages were adopted in place of the long series of live rollers commonly used. They are actuated by hydraulic rams D, whose stroke is multiplied by the intervention of chains and pulleys. The rams and cylinders are placed on the ground, a little away from the centre line of the mill. The carriage A for bringing up the ingot was a necessity under the special circumstances, inasmuch as the crane carrying the ingot is fixed, and can deliver it only at a certain point

some distance from the mill. At this point is placed the ingot cradle C, now so commonly used, but first designed and used at these works.

At the front and back of the mill, and in line with the roll housing at one side of it, are special appliances for moving the ingots or slabs. These consist of long piston-rods, having a piston at about the middle of their length, on which work long pushing cylinders P, carrying arms I and J that extend across the centre line of the mill. The arm I in front of the mill is made to rotate in a vertical plane upon the pushing cylinder, by means of a small hydraulic cylinder and ram, which can take hold of a small projection on the back of the arm when by the longitudinal movement of the pushing cylinder it is moved out to a certain distance from the rolls. The piston-rods are hollow from each side of the piston, and through apertures in them the water pressure is admitted by which the cylinders are moved. The action of the parts is as follows. The ingot carriage A is moved up to the cradle C, which has received the ingot from the crane. The cradle is turned down, and deposits the ingot on the carriage, which is then moved forward to the end of the mill, the pushing arm I having been tilted up for allowing the ingot to pass under it. The arm is then lowered behind the ingot, and water pressure is admitted into the pushing cylinder, which moves forward and pushes the ingot over the rollers up to the horizontal rolls of the mill; these seize upon it and pass it through. Then the corresponding pusher J on the other side of the mill comes into action, and pushes the ingot back again into the rolls; and this alternate action is continued until the slab is finished to the required width and thickness. All these operations are controlled by one lad at the screwing gear, one man at the pushers and carriages, one man at the mill engines with his assistant to do the necessary oiling &c., and the roller in charge of the mill. When the slab is finished, the back pusher J slides forward, takes hold of the inner end of the slab, and pulls it off the rollers and upon the carriage B which conveys it to the shears S. The carriage B is long enough to accommodate long slabs; it is supported and travels on a frame-work of girders E, of which the inner end is pivoted and the outer rests on a hydraulic ram M of short stroke, which by

raising the end of the girder frame and the carriage resting thereon enables the slab to pass forward through the shear blades, without contact with the lower blade until the shearing actually begins.

Hydraulic Slab-Shears.—In connection with the first cogging mill the author adopted hydraulic power for cutting the slabs; and when the second mill just described was constructed, shears of the same kind but much more powerful were erected. Both shears were made by Messrs. Tannett, Walker and Co., of Leeds; the larger is shown in Plate 127. On the four corners of a massive bed-plate B are placed columns supporting the cast-steel entablature E, in which are formed three cylinders, the centre one 31 inches diameter, and the two side ones each 22 inches diameter. Four strong steel bolts, passing through base-plate, columns, and entablature, bind the whole together into a firm strong structure. The rams SS for the two side cylinders are made sufficiently long to extend for some distance into the base plate; they thus act as guides to the bolster U of the upper shear-blade. The bolster is a strong steel casting; its upper centre part forms the ram C of the large centre cylinder, while the two side rams SS pass through and are attached to it by strong tap-bolts or screws. The lower bolster L is fixed on the base plate; for resisting the lateral pressure when shearing, it is supported by two strong steel castings, which are placed on the base plate under the columns, the main binding bolts passing through them. These castings are also strengthened by a strong bolt T fastened through them, parallel to the shear blades. Provision is made for holding down the after end of the slab during shearing, by a cylinder D fixed on the entablature, in which works a ram acting through a cross-head upon two rods; the latter are attached at bottom to a second cross-head, which presses down on the slab. The two side rams SS and the holding-down ram D are designed to work against constant pressure from the accumulator, and thus the return stroke is obtained. The accumulator is loaded to give a pressure of one ton per square inch. The pipes or tubes are all led to a convenient position, where all the movements are controlled by one man at the valves. On the two outer columns, and below the level of the lower shear-blade, as shown in

Fig. 8, Plate 126, brackets are provided, which support sliding brackets carrying the table that receives the slab when sheared. This table has hydraulic cylinders and rams under it, by which it is raised or lowered to suit the stroke of the shears when cutting off the slab. By the action of another ram the table after receiving the sheared slab is made to slide outwards, away from the shear blade, and into range of the hydraulic crane, which lifts the slab and loads it upon the carriage, where it is weighed and stamped, preparatory to being passed forward to the plate mill. In shears of this kind, it is important that the cut should be made as rapidly as possible; otherwise the hot slab is so long in contact with the blades that they become softened, the edges fail, and they are soon rendered useless. Hence the areas of all apertures leading to the hydraulic cylinders should be as large as possible.

Steam Slab-Shears.—Steam slab-cutting shears of great power and strength are shown in Plates 128 to 131. Those shown in Plates 128 to 130 were made by Messrs. Lamberton and Co. for Messrs. Colville and Co. of Motherwell, and are designed to cut slabs 60 inches wide by 12 inches thick. Those shown in Plate 131 were made by Messrs. Buckton and Co., to work in connection with the cogging mill at Wishaw Steel Works. Both of these shears are well designed, and embody many excellent details. The machine shown in Plate 131 will cut a hot slab up to 42 inches wide and 12 inches thick. It is driven by coupled engines, with cylinders 26 inches diameter and 30 inches stroke, through gearing with a multiplying power of thirty to one. The eccentric shaft is 20 inches diameter in the necks; the caps of the eccentric shaft are held down by four bolts of $10\frac{1}{2}$ inches diameter, passing through the uprights from top to bottom. While a slab is being cut off, it is held down on the anvil of the machine by a self-acting hydraulic-pressure foot F, giving a load of 20 tons; this prevents the slab from tilting upwards under the action of the cut. The remaining portion of the bloom rests on a roller cradle C, which is supported by a hydraulic cylinder underneath, loaded to a constant pressure of 20 tons, so that the bloom is upheld and prevented from

tilting downwards at its after end under the action of the cut. Thus both parts of the bloom are compelled to remain approximately horizontal; in consequence the severed ends are cut square, and are not sensibly scarfed. The cradle C of live rollers which supports the bloom becomes depressed under the pressure of the shear slide, and recovers its position when the slide goes up again. The cradle is arranged to feed the blooms into the machine, and the cut slabs are delivered over the anvil. The object of this arrangement is that the live rollers which feed the bloom in may be brought as close to the knives as possible. At the delivery side of the machine there is a hydraulic measuring stop M, for gauging the cut slabs to measured lengths from 6 inches to 8 feet long. It has a pointer and graduated scale for measuring; and is made with a hydraulic tilting cylinder, to swing the stop free above the travelling bloom. With this gauging stop, the bloom can be stopped while travelling on the live rollers; and can also be pushed back into exact position for cutting, and be regulated easily to a fraction of an inch.

Plate Mills.—In this country it is almost the universal practice for plates of say quarter-inch thickness and upwards to be rolled in reversing mills, especially if they are of considerable area and weight; the difficulty in handling heavy slabs and plates no doubt conduces to this practice. Whether it is the most economical method of manufacture, especially for what may be described as plates of medium thickness and weight, may perhaps be open to discussion; but for handling the heavy plates now produced it is undoubtedly the safest, and perhaps also the most economical. In Plates 132 and 133 are shown the plate mills supplied to the Wishaw Works by Messrs. Lamberton and Co., which are excellent illustrations of present practice. For general use in producing plates of medium width, the mill is provided with two stands of rolls, the finishing pair being chilled as is customary. The rolls are 8 feet long and 30 inches diameter. Both top rolls are supported on hydraulic balances, and have a lift of 18 inches. Mechanical screwing-gear is applied to the roughing rolls, and is driven by a pair of small horizontal engines geared to give the required speed. The chilled roll is screwed down by hand

in this case; but there is no satisfactory reason why the screwing should not be done mechanically at both rolls. Arrangements exist which admit of accuracy of gauge being obtained with certainty when mechanical screwing is applied to the finishing as well as to the roughing rolls. One simple method which may be mentioned is the insertion of what may be termed a short screw-jack between the chock and screw in one of the housings; a slight alteration of this, made by the roller when necessary, will at once correct any small inaccuracy in the setting or position of the main screws. Live rollers are fitted in the front and at the back of the rolls, and are driven by a pair of vertical engines conveniently placed so that the driver can see the operations at the mill. The live rollers extend a considerable distance in front of the rolls, but only a short distance at the back; here they are supplemented by live rollers fitted into a table T, Plate 132, which traverses the two sets of rolls, carrying the slab or plate across from the roughing to the finishing rolls. The table and rollers are actuated by a pair of vertical engines in the usual manner. The table travels in a pit; and its rollers being on a level with the mill floor, the finished plate is rapidly and readily delivered upon it. In a line with this mill is a stand of rolls for handling plates of the greatest weight and width. The rolls are 12 feet long and 40 inches diameter, the top one supported on hydraulic balances. The chocks are of steel with heavy brasses. This mill is fitted with mechanical screwing-gear, driven by horizontal engines which are fixed on the top of one of the housings; and it is so arranged that either of the screws can be moved alone. Hence the roller has full control, and can modify the screwing at pleasure, even to the extent of rolling plates of taper cross section if required. The arrangement is as follows: on the crank-shaft of the engines is keyed a pinion, which through a spur wheel drives the main shaft that extends over both housings; and on each of the main screws is a worm wheel, which is driven by a worm on the main shaft. These worms are loose on the shaft, and run in collar bearings in pillow blocks. They have three-pronged clutches on their outer ends, into which can engage corresponding clutches sliding on keys or feathers on the shaft; either or both of the clutches can be thrown in or out of gear, and either of the main

screws can thereby be moved or stopped at pleasure by the screwer, who stands on a platform near at hand, and obeys the instructions of the roller. The pinions P for driving both mills are placed between them. The spindles S for driving the large rolls are of considerable length, so as to reduce the angle at which they drive. They as well as their coupling boxes are of steel. In front and at back of this mill are complete sets of live rollers, driven by a pair of vertical engines E, Plate 132, which are conveniently placed for driving either these or the live rollers of the 8 feet roughing rolls, as may be required. A useful appliance is here provided for adjusting the position of the plate in front of the rolls, so that it shall pass through them as nearly square as possible, and at equal distances from the housings. Such an appliance was first designed by Mr. Duff for the large plate-mill at Blochairn Works, but has been modified for use here by Mr. Williamson. A long pusher-bar is connected to a hydraulic ram and cylinder fixed at one side of the live-roller frames; it is moved to and fro across the front of the rolls in grooves between the live rollers; holes are provided in it, into which pegs can be temporarily put, for moving the plate sideways or otherwise adjusting it. These mills are driven by a massive and powerful pair of reversing engines, constructed by Messrs. Duncan Stewart and Co., of Glasgow; they have cylinders 52 inches diameter by 60 inches stroke, and the gearing is in the ratio of two to one.

Three-High Plate Mills.—Although mills of this kind have not been adopted to any great extent in this country, it is known that they are largely employed in America; and in the author's opinion they are worthy of much more consideration than they appear to have received here. When well designed in all parts and details, the three-high mills used in the United States, which have two larger rolls at top and bottom and one smaller between them, are capable of doing more work in a given time, and probably at less cost, than the reversing mills so commonly used here. The grounds of this opinion are:—firstly, that for driving three-high mills engines can be used which are highly economical in steam consumption, and if sufficient water can be obtained they may

be triple-expansion with automatic valve-gear; secondly, the mills can be driven at a higher speed; thirdly, the loss of time due to reversing can be saved; fourthly, plates can therefore be finished more quickly, and thin plates of large area can be rolled and finished with greater accuracy of gauge and in better condition for testing; fifthly, a larger output is obtained in a given time. These are advantages of considerable importance. The disadvantages are:—firstly, that the cost of the three-high mill and its tables &c. is perhaps somewhat greater than that of the ordinary reversing mill; and secondly, that the cost of maintenance is slightly greater. But it may be repeated that, if the details were carefully designed, it is doubtful whether these disadvantages would exist at all; or if they did, whether they would be worth much consideration. It is a pleasure to see one of the three-high mills at work, when in good order; and the contrast with an ordinary reversing mill is somewhat striking. With proper appliances, few men are required, and there is little if any larger demand on their skill. The use of the three-high mills however should be limited to the production of plates of light or medium weight and of medium width.

Steam Plate-Shears.—In Plate 134 is illustrated a set of plate-shears recently supplied to Messrs. Colville and Co., Motherwell, by Messrs. Lamberton and Co., which are considered to embody some improvements. They were designed for cutting plates 2 inches thick at a gap of 37 inches. It was concluded that the ordinary form of cast-iron standard could not be relied upon to resist the strain on the material round the region of so wide a gap; hence the design here shown was adopted. The standards are formed of several pieces, which are bound firmly together by two large steel bolts, 13 inches diameter, passing from top to bottom of the machine. In the act of shearing, the whole strain is taken by these bolts, which are considered to be much more reliable than any mass of cast-iron in the form of standards could possibly be. The engines are coupled and reversing, and of sufficient power to start the cut from rest. Rams are also provided for holding the plate firmly down on the bolster during the shearing.

Hydraulic Plate-Shears.—Recently doubts have arisen whether steam-driven shears are the most suitable for the heaviest class of work, and consideration has been given to the use of hydraulic power for this purpose. A request having been made by Messrs. Beardmore for plate shears driven by hydraulic power, two or three minds appear, by one of those curious coincidences which not unfrequently occur, to have conceived simultaneously the application of hydraulic power in almost identical form. In Plate 135 is shown a design by Mr. Lamberton, in which the same general construction of standard is used as in the steam shears just described; but motion is imparted to the cutting blade through a pair of toggle arms attached to a main shaft M, whereon are keyed two levers L which in turn are connected to the rams of two hydraulic cylinders C. Pressure in an overhead hydraulic cylinder H counterbalances the weight of the apron A, and insures the return of the rams in the main cylinders C when the valve is open to the exhaust. The special feature in this machine is that by the arrangement shown the parallelism of the cutting blade is maintained throughout the whole length of a cut, which may be as long as 12 or 15 feet to meet modern requirements. Designs for a hydraulic shearing machine embodying the same principle and in almost identical form have also been recently submitted to the author by Mr. Wicksteed.

A powerful shearing machine which Messrs. Beardmore are having constructed appears also to be on the same lines, but with some novelties in construction which are of interest; they have kindly furnished the following particulars of its construction. It is of massive design, and is capable of shearing mild steel plates up to 2½ inches thick. The cheeks or standards each consist of two steel plates 14 feet by 9½ feet by 6 inches, which are separated by a cast-steel distance-piece so as to stand about 13½ feet apart from centre to centre. The gap is 37 inches wide from the edge of the bolster, and is quite open at both ends of the machine, so that a 2½-inch plate 6 feet broad and of any length can be split from end to end with ease. The motive power is supplied by two upright cast-steel hydraulic cylinders, 20½ inches internal diameter by 4½ feet stroke, firmly snugged and bolted to the back of the cheeks. The hydraulic pressure

is transmitted from each ram to the blade or apron through a lever having a mechanical advantage of three to one. Both levers are rigidly keyed to one common shaft, 18 inches diameter and 18 feet long, which passes from end to end of the machine, and is supported by cast-steel brass-lined bearings passing through the cheeks and bolted firmly to them. Any tendency to thrust the blade endwise will be resisted by the torsional rigidity of the main shaft. The ram of each cylinder is in the form of a trunk piston, to which is secured a mild-steel connecting-rod. The water under a pressure of 700 lbs. per square inch acts on an area of 330 square inches on the underside of each ram, while there is a constant back-pressure of 700 lbs. per square inch on an annular area of 47 square inches on the upper side of the ram, thereby enabling the blade to be lifted when the pressure on the lower side of the ram is relieved. The effective pressure on the lower side of each ram is thus $88\frac{1}{2}$ tons. The total pressure therefore transmitted to the blade at any instant is upwards of 530 tons; and as the cutting edge has an inclination of 1 in 9, the intensity of pressure per square inch on the section of say a 2-inch plate in the process of being sheared will be approximately 30 tons, which allows an ample margin for friction in the working parts. While the plate is being sheared, it is held steadily against the bolster by three small hydraulic cylinders, which together exert a pressure of 10 tons, and are bolted firmly to the front guide of the machine. Arrangements are under consideration whereby a mild-steel plate of any dimensions and of thickness up to 2 inches can be taken from the mill-house floor, sheared on all four edges, and deposited again on the floor, with the aid of only one man and a boy.

It is a question worthy of consideration whether plates of such great thickness should be subjected to shearing. Familiarity with the use of mild steel has removed the nervousness which led in its earlier days to the exercise of great care in its treatment. It is now an axiom that in good work steel plates should not be punched; or if they be, then rimering must follow to remove the injured portions around the hole. Shearing is detrimental to the edges of plates, especially when the shearing blades are in bad order; and the injury

is greater with such thick plates as those under consideration, and should be removed by subsequent planing. These considerations induced the author to hesitate in adopting the shearing process for thick plates, and rather to prefer ripping machines for the purpose, thus avoiding the injury although at a slightly increased cost.

Hydraulic Forging-Press Cylinder.—Hammers, which since the introduction of cogging mills have fallen into desuetude for making steel slabs to be rolled into plates, are also being gradually displaced for other work by the increasing use of hydraulic forging presses; and in connection with the construction of a most powerful press, Messrs. Beardmore have taken a step which it may be of interest to mention. In Plate 137 is shown the cylinder which has been cast for the press. Apart from the successful casting of such a large and heavy cylinder, there is the additional interest that it is of nickel steel, and is probably the heaviest piece yet cast of this material, certainly in the form of a difficult casting. The weight of the casting with head is 64 tons, and the finished weight of the cylinder will be 42 tons. A test of the actual casting has not yet been made; but a portion of the charge was run into an ingot 23 by 18 inches, then cogged down to a billet 5 by 7 inches, and from this the following test results were obtained:—tensile strength 40·1 tons per square inch; elongation in 8 inches length 20 per cent.; elastic limit 55·8 per cent. of tensile strength; contraction of area 43·4 per cent.; and Lloyd's bending test was stood without fracture. This product of Messrs. Beardmore's skill and enterprise is peculiarly interesting to the author, seeing that it confirms his expectation of the service which nickel steel may render to engineering work.

Discussion.

Mr. E. WINDSOR RICHARDS, Vice-President, believed the different kinds of machinery described in the paper were now in use at several steel works in this part of the country. As to the adoption of the three-high rolls for plate mills in America, while in England the two-high reversing mills were still adhered to, there was of course a great deal of difference in the plates turned out in America and in England. For the limited range of sizes of plates made in America the best form of mill undoubtedly was the three-high non-reversing mill with fly-wheel. The American mills had not yet been called upon to produce the diversity of work required in England. When in America ten years ago he saw at the Cleveland Iron Works on Lake Erie a powerful three-high mill, and found that there was not much variety in the sizes of plates it was supplying; they were for ships on the lake, which were nothing like the kind of ships built on the Clyde. There the plates were being rolled direct from the ingots. The ingot was cast in the form of a flat slab, ready at once for the plate rolls; there was no cogging mill of any description. The bloom or slab was rolled forwards and backwards in the three-high mill, which had a smaller roll between the two larger rolls; and the work was done satisfactorily. That kind of mill however was adapted only for long and comparatively thin plates. In this country, except in the largest steel-works and where all kinds of plates had to be supplied, the reversing mill he thought would certainly be adopted for general work. There was no doubt that the reversing mill was not applicable, as hinted in the paper (page 444), for long thin plates. In deciding upon the kind of mill to be adopted, it was therefore necessary to know beforehand what would be the sizes of the plates to be rolled.

Mr. LEWIS RICHARDS noticed that in the direction of economy of steam in rolling-mill engines it appeared from the paper (page 437) that not much had been done in the reversing-mill engine. The most that had been done he believed had been to raise the boiler

(Mr. Lewis Richards.)

pressure from about 50 lbs. per square inch to 80 lbs., and in some instances even to 100 lbs. No great economy he considered could result from this course, unless the steam was also used expansively: it did little more than reduce the size of the cylinders, and consequently the work done against back-pressure. It also gave a greater range of power with a given size of cylinder, which was of considerable importance in a rolling mill, where the load was so variable. As to the coal consumption mentioned of 3 lbs. per I.H.P. per hour, it would doubtless be interesting to many engineers besides himself to learn how this figure had been arrived at. The coal consumption per horse-power in a rolling-mill engine had always been looked upon by himself as difficult to ascertain. The work at the rolls was so variable that it seemed almost impossible to get a reliable average diagram of the power. In this respect a rolling-mill engine was so different from the engines of a steamship or a cotton mill; and moreover there were continually intervals during which no useful work was being done at the rolls, while the boilers were still burning coal.

Mr. JEREMIAH HEAD, Past-President, considered this a most valuable paper on a subject in which there was no man who had had greater experience than the author, either in England or in any other country. Besides reviewing recent improvements in the rolling of steel, especially of plates, in Scotland and in the north of England, where the lead had been taken in this special industry for many years, the paper had also referred to what was being done in America in some instances; while Mr. Windsor Richards had alluded to what he had seen there some years ago. Having himself recently returned from a tour in America, undertaken for gaining information on this very subject, he was able to say that there, as here, the great thing to be noticed was the absolute necessity for all works of this kind to be kept thoroughly up to date. Works which had been built say twenty years ago, and had at that time taken the lead and been able to make a large profit, were now, if they had done nothing except keeping in repair, entirely outstripped in the race, and had no chance whatever of doing anything but losing. In the manufacture

of plates it was there almost universally the practice now to roll them from flat ingots cast from the bottom. The only exception that he had seen, though there might be others, in which a cogging mill was used, was at Carnegie's works at Homestead; elsewhere exceptionally good plates were being produced by simply rolling from flat ingots. It would be remembered that in this country a similar plan was a good deal in use about fifteen or twenty years ago, but was abandoned under the belief that the Lloyd's and Board of Trade tests could not be assured without the preliminary process of cogging, especially in thick plates; therefore cogging mills had become universal in this country. In America he had ascertained that plates rolled direct from flat ingots were subjected to the tests of the Bureau Veritas, equivalent to Lloyd's, and that no trouble had been experienced with them. This he thought was an interesting matter.

In regard to the yield, he was informed that the ordinary proportion of saleable plates obtained from the weight of ingots used was from 65 to 68 per cent. It would be interesting if the author would say something on this subject. At Carnegie's works, where cogging was practised, he had been told that the yield of saleable plates obtained was 68 per cent.; and at other works, where flat ingots were rolled without cogging, it was from 65 to 66 per cent. One of the ways in which plates could be made most economically on a large scale was by subdividing the work, so that the whole of the plates, light and heavy, broad and narrow, long and short, were not necessarily made in one and the same mill. At one of the principal Pittsburg works they were all rolled in three mills: one was a large mill for plates of various sizes; another was a Belgian universal mill, reversing; and a third was an ordinary sheet mill. In that way good work seemed to be done without any cogging.

In regard to reversing as against the three-high system, the plate mills in the United States were universally three-high, as far as he had seen and heard. He had gone there rather predisposed in favour of reversing mills, with which in the Cleveland district the best practice he believed was to make about 1,500 tons of plates with a cogging mill in a week. At the Homestead works at Pittsburg,

(Mr. Jeremiah Head.)
with a three-high mill and a cogging mill, the production reached was as high as 1,700 tons in a week, with an average of 1,500 tons a week. On this point also some information from the author would be interesting. The slab shears in America, as far as he had seen, were almost universally hydraulic, and cutting upwards from below. Another thing which had struck him was that it was not the custom there to have any plate mills with both roughing and finishing rolls: the whole work was done in a single set of three rolls. Whether the plates were rolled from flat ingots or from slabs, they were passed only through a single set of rolls from beginning to end. Still another thing which had struck him was that, after the finished plate had left the mill, it was not laid on the floor to cool, as was the custom in this country. Here the cooling consequently required a large floor, if there were a great quantity of plates turned out; and as the cooling was mainly done from the upper surface of the plate, while the underside cooled more slowly, the floor soon got hot. But in America the train of live rollers was continued from the mill to the back of the shears, and the plates lay in a string to cool on the live rollers. In that way the bottom as well as the top of the plate was cooling all the time; therefore the plate cooled in half the time. The distance from the mill to the shears, in one place where he measured it, was 120 yards of live rollers with plates cooling all the way along. On arriving at the far end, they passed through the back of the shears; the ragged end was cut off, and the plate was cut in the middle if required. On the other side of the shears were provided a number of rollers on castors, on which the sheared plates were turned round for shearing the sides, and afterwards wheeled away in any direction by a few men. If a great quantity of work was going through the shears, the plates were turned round after the ends had been sheared, and were passed on to another subsidiary shears which cut the sides. The handling on the plate bank was largely done in that way; and also with electric cranes, in the most advanced works. Little use was made of bogies for conveying the plates, or of forks for shifting them. The electric cranes in some works used magnets for lifting, fitted up according to the lifting power required: an electro-magnet was lowered upon the top of a plate or

other piece of iron to be lifted, and was made into a magnet by passing a current round it. Weights up to 25 tons were sometimes lifted in that way. The shears in the modern works were all of massive size, and all able to cut up to two inches thick. The gaps were as much as three feet, and the widths between the cheeks or standards up to ten feet. It had been remarked by Mr. Windsor Richards (page 451) that three-high rolling mills were not adapted for broad plates; but he had himself measured some that were ten feet wide, which had been made in three-high mills: in fact there was no other kind of mill in operation there. In making armour plates, forging presses were now being used entirely for all thicknesses above four inches. Although the United States had not the great shipbuilding trade of England, requiring large quantities and many varieties of ship plates (page 451), still the ships that were used on the great Lake had much increased in size since Mr. Richards was there ten years ago. He had himself just been over two ship-yards at Cleveland on Lake Erie, in one of which a cargo ship was building of 4,000 tons burden, and there were plates in her hull up to an inch thick.

Mr. Alfred Saxon considered that, in connection with the notes in the paper (page 437) with reference to rolling-mill engines, in no class of machinery was so much friction absorbed as in rolling mills. He should be glad to know whether the author had tested any rolling-mill engines running light at a proper speed without doing any work. In one or two instances which had come under his own notice he had been surprised at the great amount of friction in comparison with engines and gearing used for other purposes, such as cotton mills. For rolling plates generally, he believed that direct-driven mills with fly-wheels were preferable to geared mills or to reversing mills of any kind.

In favour of three-high plate mills it was urged in page 446 that for driving three-high mills engines could be used which were highly economical in steam consumption; and it was added that, if sufficient water could be obtained, they might be triple-expansion. The latter remark seemed to him to require modifying, inasmuch

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(Mr. Alfred Saxon.)
as the supply of water for condensation affected not only triple-expansion, but equally two-cylinder compound and simple condensing engines. The employment of triple-expansion engines turned rather upon the steam pressure that was available; and in reality rather less condensing water he considered could be used in most triple-expansion engines than in two-cylinder compound or simple condensing engines.

Mr. ANDREW LAMBERTON, referring to the statement made in page 448 as to the coincidence of two or three minds having simultaneously conceived the application of hydraulic power to plate shears in almost identical form, was glad to assure Mr. Wicksteed that, in working out the design of the shears shown in Plate 135, he had done so in absolute ignorance of the fact that Mr. Wicksteed was also working on the same lines; and he was also sure that Mr. Wicksteed was unaware of what he was himself doing in this direction. So far the coincidence was remarkable. In regard to Messrs. Beardmore's design he was unable to offer the same explanation, having submitted to them a full drawing of his own form of shears nearly a month before their plan had been decided upon, of which a description was given in the paper.

Mr. RALPH H. TWEDDELL said that, besides the three designs just referred to, there was a fourth candidate in the field in connection with the same idea of working plate-shears by hydraulic power Messrs. Fielding and Platt, in conjunction with himself, had also hit upon a plan, including an arrangement for maintaining the required parallelism of the cutting blade in a manner which they thought elegant and simple; and he did not know of its having been adopted anywhere else. As shown in Figs. 24 and 25, Plate 136, the plan consisted of a horizontal hydraulic cylinder C and ram, bolted to one side of the framing of a plate-shearing machine. The slide S, carrying the upper or moving shear blade, worked vertically in suitable guides in the framing. On the top of the slide were three inclined planes P, and immediately over these were three corresponding inclined planes fixed underneath the top girder of

the framing. The ram of the hydraulic cylinder pushed forwards by means of a thrust rod a long cross-head or longitudinal frame F, carrying three pairs of rollers R; the two rollers in each pair, one above the other, were in contact with each other, and worked between the facing inclines, against which they bore, thereby forcing the shearing slide S vertically downwards through the extent of its stroke. The slide was kept up in contact with the lower rollers by a vertical hydraulic draw-back cylinder and ram, fixed on the top of the frame and acting with a constant lifting pressure, being connected with the shearing slide by a cross-head and side-rods. When the pressure was removed from the cylinder C, the frame F and rollers were forced back by the action of the draw-back cylinder in lifting the shearing slide. This arrangement was applicable alike to punching, shearing, bending, and other such machines, a number of which had already been made; and it was found that there was little or no end thrust on the moving slide, nor had it any tendency to tilt vertically out of parallel, by one end moving down or up faster than the other, inasmuch as by the pressure on the rollers and on the inclined planes the inclines on the top of the slide were kept in their true position relatively to the fixed inclines on the framing above them.

Mr. J. Hartley Wicksteed, Vice-President, corroborated Mr. Lamberton's representation of their mutual independence in regard to the design of the hydraulic plate-shears, however closely identical their two arrangements might seem. In the design of the heavy shears shown in Plate 134, it was stated in page 447 that in the act of shearing the whole strain was taken by the two large steel bolts of 13 inches diameter, which rendered the machine much stronger than it could possibly be made by any mass of cast-iron in the form of standards. Clearly that was a convenient way of bolting castings together, which were too unwieldly to cast all in one piece in an average foundry. But in the construction here shown he disputed the fact of the bolt making the machine stronger; on the contrary he thought it really made it weaker, for the reason that it did not actually take the strain off the casting.

(Mr. J. Hartley Wicksteed.)
The strain in shearing was between the eccentric shaft above and the shearing bolster below; and this strain was not purely vertical, because there was also a great deal of pressure tending to force the faces of the blades away from each other in a horizontal or longitudinal direction; and the resultant strain was therefore an oblique strain inclined at a considerable angle to the vertical. What had had to be done, in order to insert the large steel bolt, had been to perforate the casting throughout from top to bottom; and he did not know any reason why the whole casting should not break away across the portion just in front of the bolt, either through the top at AA or through the bottom at BB. Another place where the fracture might come was at E, through the eyelet carrying the bearing of the eccentric shaft, where the direct pressure came: in either case leaving the bolt undisturbed. It was true he had himself adopted binding bolts in the construction of the hot shears shown in Plate 131; but he had done so in a totally different way. It would be seen that the shears were bolted together with four bolts, and these were at the two ends of a massive cap, which formed a girder across the top of each end of the eccentric shaft. The point of most intense pressure on this cap or girder was in the centre; and he could therefore afford to perforate the girder at the two ends, and put bolts through it there. A good reason for so doing was that, in hot-bloom shears where the great heat of the passing blooms expanded the inside webs of the standards unequally with their outsides, if a joint were not made to begin with, the machine when put to work would soon make a joint for itself; it was therefore a good thing to have two long bolts passing right through the ends of the cap.

Besides other valuable remarks in regard to hydraulic shearing, the author had also pointed out in page 443 that a matter of importance in shearing hot slabs was speed, because if the shearing blades were in contact with the hot bloom for too long a time they lost the keen edge necessary to make a clean cut. It would be interesting to know what was the speed necessary; and whether a satisfactory speed could be obtained with the hydraulic arrangement.

With the rotary arrangement of steam-driven shears the engine could be run up to 180 revolutions per minute; and it was indeed necessary to run it fast in order to do the work. At the same time, being worked by an eccentric the descending blade passed the bottom centre without any shock, and reversed itself with equal smoothness. As to whether in the hydraulic shears there was a sufficiently large valve to get rid of the exhaust water with sufficient speed, this was a question on which he should like to have more information.

Mr. Riley said that, in giving the paper the title of "notes" on modern steel-works machinery, his object had been not to express many opinions, but rather to collect the results of experience in different directions.

As to the accuracy of indicator diagrams from rolling-mill engines (page 452), all engineers knew the difficulties alluded to by Mr. Lewis Richards. The gist of the statement made in the paper was that at least one-half, if not three-fourths, of the steam formerly used had now been saved by the adoption of improved arrangements, the value of which would probably be appreciated from the result.

It was difficult to answer Mr. Head's question (page 453) with regard to the percentage of good plates obtained by the different processes of manufacture, namely by direct rolling from the ingot, or with the intervention of the cogging mill. Though he could not himself furnish the exact figures, he thought Mr. Head's percentages were not far wrong. It had been proved long ago that, with the variety of steel plates which had to be made in large works in this country, the same results could not be obtained by rolling direct from the ingot as with the intervention of the cogging mill. Ten years ago, when the variety of plates required was not so great as at the present day, the proprietor of the Cleveland Iron Works on Lake Erie being on a visit to England had confessed that it would be impossible for him to conduct his works by rolling plates from ingots direct, if he had the same variety of sizes to turn out as then had to be produced in England; and that variety, as all engineers knew, had been largely increased during the last few years.

(Mr. Riley.)

Another remark of Mr. Head's was valuable (page 453): namely that, as many plate-rollers had found in their own experience, it was better to have a small mill to do small plates, a medium-size mill for medium plates, and a large mill to roll large plates. It was particularly to the medium-size mill that he was referring in the paper (page 447), when he recommended strongly, as he considered it deserved, the three-high mill.

The method referred to by Mr. Head of conveying the plates on live rollers for a considerable distance, during which they were cooling before arriving at the shears (page 454), was undoubtedly a plan which would commend itself in many instances. But here again he considered such a method was not adapted to the conditions that had to be dealt with in this country; and he believed that in the works where Mr. Head had seen that plan in operation, when they had gone more extensively into plates for shipbuilding and other purposes of construction as they were now doing in the United States, it would ultimately be found that there was a great deal of inconvenience in that mode of dealing with hot plates.

He was much obliged to Mr. Saxon for bringing forward the points he had raised (page 455) in reference to rolling-mill engines; and he entirely agreed with what he had said. Most engineers who had had to do with rolling mills, he was sure, had taken frictional diagrams of their engines, though he could not quote the exact horse-power which was required to drive either the pull-over or the reversing mill; it depended of course upon the particular circumstances and conditions of the individual mill.

With regard to the speed of the hydraulic shears, it would be difficult to answer Mr. Wicksteed's question (page 458) in a satisfactory manner; and all he had been able to do in the paper had been to refer to this point in general terms.

The PRESIDENT was sure the Members would give Mr. Riley a cordial vote of thanks for his paper, the interest of which was greatly increased by the kind invitation, of which he knew many members intended availing themselves, to visit the steel works now under the author's own care.

Mr. Riley said it was due to the gentlemen who had kindly furnished him with their designs for the machinery described in the paper that the vote of thanks just passed to himself should be considered as conveyed to them also.

EXCURSIONS.*

On TUESDAY AFTERNOON, 30th July, after luncheon in the Institute of the Fine Arts, four alternative visits were made. The first was to the Reservoirs of the Glasgow Water Works at Milngavie (page 468), under the guidance of Mr. James M. Gale, Engineer of the Glasgow Corporation Water Works, to inspect the works already completed and those in course of construction.

The second alternative visit was to the Glasgow Sewage Works (page 473), under the guidance of Mr. Thomas Melvin, General Manager; and afterwards to the Dalmarnock Iron Works, under the guidance of Mr. Thomas Arrol, Jun.

The third visit was to the Shipbuilding Yards at Govan, of the London and Glasgow Engineering and Iron Shipbuilding Co.; of the Fairfield Shipbuilding and Engineering Co. (page 502); and of Messrs. Alexander Stephen and Sons, Linthouse (page 510).

The fourth visit was to the Dawsholm Gas Works, Maryhill (see pages 331–352), under the guidance of Mr. William Foulis, General Manager of the Glasgow Corporation Gas Department.

The following Works in Glasgow and the neighbourhood were opened to the visit of the Members this afternoon, as also on Wednesday afternoon, and on Thursday. Descriptions of most of these are given in pages 471–531.

Messrs. Alley and MacLellan, Sentinel Engine Works, Polmadie Road.

Messrs. Barclay, Curle and Co., Ship Yard, Clydeholm, Whiteinch; Boiler Works, 90 Kelvinhaugh Street; and Stobcross Engine Works, 36 Finnieston Street.

Caledonian Railway Locomotive Works, St. Rollox.

Dalmarnock Iron Works, Bridgeton.

Dawsholm Gas Works, Maryhill.

Messrs. Dübs and Co., Glasgow Locomotive Works.

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* The notices here given of the various Works &c. visited in connection with the Meeting were kindly supplied for the information of the Members by the respective proprietors or authorities.

Messrs. James Dunlop and Co., Clyde Iron Works, Tollcross.

Electric Lighting Station, 75 Waterloo Street.

Messrs. D. and W. Henderson, Meadowside Ship Yard, Partick; and Engineering Works, 190 Elliot Street, Finnieston.

New Howe Machine Co., Cycle Works, 128 Avenue Street, Bridgeton.

Hyde Park Foundry, 54 Finnieston Street.

Hydraulic Power Supply Pumping Station, High Street.

Messrs. A. and J. Inglis, Point House Ship Yard.

Messrs. Mavor and Coulson, Electrical Engineering Works, Bridgeton Cross.

Messrs. M'Dowall, Steven and Co., Milton Iron Works, 142 North Woodside Road.

Messrs. McOnie, Harvey and Co., Scotland Street Engine Works, South Side.

Messrs. Mechan and Sons, Neptune Works, 60 Elliot Street, Cranstonhill.

Mirrlees, Watson, and Yaryan Co., Scotland Street Iron Works, South Side.

Messrs. Muir and Houston, Harbour Engine Works, 60 Portman Street, Kinning Park.

Messrs. Napier Brothers, Windlass Engine Works, 100 Hyde Park Street.

Messrs. Neilson and Co., Hyde Park Locomotive Works, Springburn.

North British Railway Locomotive Works, Cowlairs.

Messrs. Penman and Co., Caledonian Iron Works, Strathclyde Street, Dalmarnock Road.

Messrs. David Rowan and Son, Marine Engine and Boiler Works, 231 Elliot Street.

Sewage Purification Works, Swanston Street, Dalmarnock.

Messrs. Sharp, Stewart and Co., Atlas Works, Springburn.

Messrs. A. and W. Smith and Co., Eglinton Engine Works, 57 Cook Street.

Messrs. Hugh Smith and Co., Possil Engine Works.

Steel Company of Scotland, Steel Works, Hallside, Newton; and Blochairn.

Messrs. Steven and Struthers, Anderston Brass Foundry, 34 Elliot Street, Anderston.

Messrs. Duncan Stewart and Co., London Road Iron Works, Bridgeton.

Messrs. D. Y. Stewart and Co., Ironfoundry, Charles Street, St. Rollox.

Messrs. John Tullis and Son, St. Ann's Leather Belt Manufactory, John Street, Bridgeton.

Messrs. John Ure and Son, Regent Flour Mills, Sandyford.

Messrs. George and James Weir, Holm Foundry, Cathcart.

Messrs. James White, Philosophical Instrument Factory, 18 Cambridge Street.

Messrs. Anderson and Lyall, Clydeside Engine and Boiler Works, Whitefield Road, Govan.

Messrs. Lindsay Burnet and Co., Moore Park Boiler Works, Helen Street, Govan.

Messrs. William Dixon, Govan Iron Works.

Messrs. Dunsmuir and Jackson, Govan Engine Works, Windsor Street, Govan.
Fairfield Shipbuilding and Engineering Works, Govan.
London and Glasgow Engineering and Iron Shipbuilding Works, Govan.
Messrs. Mackie and Thomson, Govan Shipbuilding Yard.
Messrs. Ross and Duncan, Whitefield Works, Govan.
Messrs. Alexander Stephen and Sons, Shipbuilding Yard, Linthouse, Govan.
Glasgow Water Works, Milngavie.
Messrs. William Baird and Co., Gartsherrie Iron Works, Coatbridge.
Glasgow Iron and Steel Works, Wishaw.
Summerlee and Mossend Iron and Steel Works, Mossend.
Messrs. John Watson, Earnock Colliery.
Messrs. William Denny and Brothers, Ship Yard, Dunbarton.
Messrs. Denny and Co., Engine Works, Dunbarton.
Singer Manufacturing Co., Sewing-Machine Works, Kilbowie.
Messrs. J. and G. Thomson, Shipbuilding Yard and Engineering Works, Clydebank.
Messrs. Lobnitz and Co., Shipbuilding Yard, Renfrew.
Messrs. W. Simons and Co., London Works, Renfrew.
Messrs. Bow, McLachlan and Co., Thistle Engine Works, Paisley.
Messrs. Clark and Co., Anchor Thread Works, Paisley.
Messrs. A. F. Craig and Co., Caledonia Engine Works, Paisley.
Messrs. Fleming and Ferguson, Phœnix Ship-Yard and Engine Works, Paisley.
Messrs. John Fullerton and Co., Merksworth Shipbuilding Yard, Paisley.
Messrs. Fullerton, Hodgart, and Barclay, Vulcan Works, Renfrew Road, Paisley.
Messrs. John Lang and Sons, Lathe and Tool Works, Johnstone.
Messrs. John M'Dowall and Sons, Walkinshaw Foundry, Johnstone.
Messrs. Thomas Shanks and Co., Union Iron Works, Johnstone.
Messrs. David J. Dunlop and Co., Inch Works, Port Glasgow.
Messrs. Russell and Co., Kingston Shipbuilding Yard, Port Glasgow.
Messrs. Caird and Co., Shipbuilding Yard and Engine Works, Greenock.
Messrs. Scott and Co., Shipbuilding Yard and Engine Works, Greenock.

In the evening the Institution Dinner was held in the Windsor Hotel, and was largely attended by the Members and their friends. The President occupied the chair; and the following Guests accepted the invitations sent to them, though those marked with an asterisk * were unavoidably prevented at the last from being present.

The Honourable the Lord Provost, Sir James Bell, Bart.; Bailie Primrose, Senior Magistrate; Mr. Hugh Brown,* Lord Dean of Guild; Sir John N. Cuthbertson.

Executive Committee.—Sir Renny Watson, *Chairman*; Mr. John Inglis,* *Vice-Chairman*; and Professor Archibald Barr, D.Sc., *Honorary Secretary.* Mr. Stephen Alley*; Mr. William Arnot; Sir William Arrol, LL.D., M.P.; Mr. Richard Barnwell*; Mr. William Beardmore; Mr. Andrew S. Biggart; Mr. G. MacLellan Blair; Mr. William Brown*; Mr. Patrick T. Caird; Mr. Robert Caird; Mr. James Deas; Mr. Archibald Denny*; Mr. Peter Denny, Jun.; Mr. Dugald Drummond*; Mr. Charles R. Dübs; Mr. Robert Dundas*; Mr. David J. Dunlop*; Mr. William Foulis; Mr. James M. Gale; Mr. George Graham; Mr. John Hamilton; Mr. Robert Harvey; Mr. Matthew Holmes; Mr. James G. Jenkins; Mr. Thomas Kennedy; Mr. John Laidlaw; Mr. Robert Laidlaw; Mr. Andrew Laing; Mr. William Lorimer; Mr. George McFarlane; Mr. Robert Maclaren; Professor Alexander MacLay, B.Sc.; Sir Andrew Maclean; Mr. James Manson; Mr. Henry A. Mavor; Mr. William Melville*; Mr. W. J. Millar; Mr. James Mollison; Mr. George Neilson; Mr. James Neilson; Mr. Hugh Reid*; Mr. David Richmond*; Mr. James Riley; Mr. John F. Robinson; Mr. Anderson Rodger; Mr. James Rowan; Mr. Edmund Sharer*; Mr. John W. Shepherd; Mr. William Smith*; Mr. John Stephen*; Mr. L. Sterne* Mr. Duncan Stewart; Mr. C. E. Stromeyer; Mr. James M. Thomson; Mr. James R. Thomson*; Mr. John Turnbull, Jun.; Mr. Hugh Wallace.*

Mr. Henry R. J. Burstall; Mr. Edward B. Ellington; Professor William Stroud, D.Sc.

Mr. James Nicol, City Chamberlain; Mr. Francis Braid, Postmaster; Mr. David Cooper, General Manager, Glasgow and South Western Railway; Mr. Robert Currer,* District Superintendent, Caledonian Railway; Mr. W. H. Inslee, General Manager, Singer Sewing-Machine Works; Mr. Irvine Kempt,* General Superintendent, Caledonian Railway; Mr. John F. M'Intosh, Locomotive Superintendent, Caledonian Railway.

The President was supported by the following Officers of the Institution:—*Past-President*, Mr. Jeremiah Head; *Vice-Presidents*, Mr. Edward P. Martin, Mr. E. Windsor Richards, and Mr. J. Hartley Wicksteed; *Members of Council*, Mr. Benjamin A. Dobson,

Mr. Bryan Donkin, Mr. William H. Maw, Mr. James Platt, and Mr. A. Tannett Walker.

After the usual loyal toasts, the President proposed "The Honourable the Lord Provost and the Corporation of Glasgow," which was acknowledged by the Honourable the Lord Provost, Sir James Bell, Bart. The toast of "The Clyde Industries," proposed by Mr. E. Windsor Richards, Vice-President, was acknowledged by Sir William Arrol, LL.D., M.P.; Mr. James Riley, President of the West of Scotland Iron and Steel Institute; and Mr. John W. Shepherd. Mr. Edward P. Martin, Vice-President, proposed the toast of "The Executive Committee," which was acknowledged by Sir Renny Watson, Chairman, and Professor Archibald Barr, D.Sc., Honorary Secretary. The toast of "The Institution of Engineers and Shipbuilders in Scotland," proposed by Mr. J. Hartley Wicksteed, Vice-President, was acknowledged by Mr. James Rowan, Vice-President of the Institution of Engineers and Shipbuilders in Scotland. Bailie Primrose, Senior Magistrate, proposed the final toast of "The President."

On WEDNESDAY AFTERNOON, 31st July, after luncheon in the Institute of the Fine Arts, alternative visits were made to Locomotive and other Works. One party visited Messrs. Neilson and Co.'s Hyde Park Locomotive Works, Springburn (page 481), under the guidance of Mr. Hugh Reid; and Messrs. Sharp, Stewart and Co.'s Atlas Works, Springburn (page 484), under the guidance of Mr. John F. Robinson. Another party visited the Caledonian Railway Works, St. Rollox (page 476), under the guidance of Mr. John F. M'Intosh, Locomotive Superintendent; and the North British Railway Works, Cowlairs (page 482), under the guidance of Mr. Matthew Holmes, Locomotive Superintendent. A third party made a visit to Messrs. Dübs and Co.'s Glasgow Locomotive Works (page 478), under the guidance of Mr. Charles R. Dübs and Mr. William Lorimer; and to Messrs. Alley and MacLellan's Sentinel Engine Works, Polmadie Road (page 486), under the guidance of Mr. John A. MacLellan.

An alternative Excursion was made by special train on the new West Highland Railway to Ardlui Station at the head of Loch Lomond, by special steamer "Prince Consort" from Ardlui to Balloch at the foot of Loch Lomond, and thence by special train to Glasgow.

On THURSDAY, 1st August, two alternative Excursions were made. One was by special train to Clydebank to visit Clydebank Shipbuilding Yard and Engine Works (page 512), under the guidance of Mr. James R. Thomson. After luncheon in the Clydebank and Yoker Public Hall, one party visited the Singer Sewing-Machine Works, Kilbowie (page 511), under the guidance of Mr. W. H. Inslee, General Manager; while another party proceeded by special train to Dunbarton, and visited Messrs. Denny and Co.'s Engine Works, under the guidance of Mr. Walter Brock, and Messrs. William Denny and Brothers' Ship Yard, under the guidance of Messrs. Denny.

Another Excursion was made by special train to Wishaw, where the Works of the Glasgow Iron and Steel Co. were visited, under the guidance of Mr. James Riley, General Manager. After luncheon at the Works, by invitation of the Glasgow Iron and Steel Co., a visit was made to the Works of the Summerlee and Mossend Iron and Steel Co., under the guidance of Mr. James Neilson.

In the evening the Members were invited by the Honourable the Lord Provost, Sir James Bell, Bart., and Lady Bell, to a Conversazione in the Municipal Buildings.

On FRIDAY, 2nd August, an Excursion was made on the Firth of Clyde, by invitation of the Chairman and Members of the Executive Committee. The party proceeded by special trains to Princes Pier, Greenock, whence a cruise was made in the "Glen Sannox" to the coast of Arran, returning by Loch Fyne and the Kyles of Bute.

On Saturday morning, 3rd August, the Edinburgh Corporation Electric Lighting Station was open to the visit of the Members, under the guidance of Mr. E. W. Monkhouse, Resident Engineer.

GLASGOW CORPORATION WATER WORKS, LOCH KATRINE.

The act of parliament for the construction of the first Loch Katrine Water Works was obtained in 1855, and the works were completed and opened by Her Majesty on 14th October 1859. Loch Katrine is situated in Perthshire about 30 miles north of Glasgow, and is the principal of a chain of three lochs, lying in the same valley and forming the right branch of the river Teith; the other two are Loch Achray and Loch Vennachar, Plate 138.

Power was obtained to raise Loch Katrine 4 feet above the previous summer level, and to draw it down 3 feet below, thus giving a total available depth of 7 feet of water, and providing storage for 5,623 million gallons. For the purpose of providing compensation water to the riparian owners on the river Teith, power was also obtained to raise Loch Vennachar 5 feet 9 inches above its previous summer level and to draw it down 6 feet below; and also to raise Loch Drunkie 25 feet, a small loch lying to the south of Loch Vennachar. The quantity of water thus made available was sufficient to maintain a supply of 50 million gallons per day for Glasgow and 40½ million gallons per day for compensation to the river Teith.

The point at which the aqueduct leaves Loch Katrine is about 5 miles above the outlet. It is 8 feet wide and 8 feet high throughout with a semi-circular top, and has a fall towards Glasgow of 10 inches per mile. It is 25⅝ miles long, and discharges into the service reservoir at Mugdock near Milngavie, about 7 miles from Glasgow. There are three valleys on the line of the aqueduct, together about 3⅝ miles long; and these are crossed by three parallel lines of cast-iron pipes. Considerable portions of the

aqueduct are in tunnel; and where the rock was hard enough, lining was dispensed with. The rough surface of the rock cuttings however has a prejudicial effect upon the velocity of flow of the water.

At the Mugdock reservoir the water is first discharged into a basin, from which it passes over cast-iron gauge-plates 40 feet wide, brought to a thin edge, over which the depth of water passing is regularly recorded and the discharge computed. The reservoir is 317 feet above sea level; it has a water surface of 60 acres, a depth when full of 50 feet, and contains 548 million gallons, or about eleven days' supply to Glasgow at 50 million gallons per day. It thus admits of repairs being done upon the aqueduct, without interrupting the supply of water to the city.

The water is drawn from the reservoir into a circular well cut out of the rock, 40 feet diameter and 63 feet deep, fitted with copper wire-cloth strainers, through which the water passes. Thence it is conveyed by two lines of 42-inch pipes laid in a tunnel 420 yards long, and then by four lines of 36-inch pipes to the city. These are together capable of discharging 50 million gallons per day. The works cost £1,330,000.

At the end of 1881 Glasgow had increased in population so greatly that it became apparent a larger supply of water than the aqueduct could convey from Loch Katrine would be required within a few years. Accordingly an act was obtained in 1882 for the construction of an additional service reservoir adjoining the Mugdock reservoir. In 1885 a further act was obtained which gave power to duplicate the aqueduct, to raise the level of the water in Loch Katrine 5 feet higher, and to convert Loch Arklet into a reservoir by raising its water level 25 feet. Loch Arklet adjoins Loch Katrine on the west, but drains into Loch Lomond and thence into the river Leven.

The new works were laid out with the view of an ultimate supply to the city of 100 million gallons per day; and in order to admit of repairs being made upon the aqueducts, the new one has been made large enough to convey 70 million gallons per day. It consists of a succession of tunnels, which for the greater part were

driven from the ends without shafts, the drills being worked by compressed air, at a pressure of about 60 lbs. per square inch. It is $23\frac{1}{2}$ miles long to the service reservoir, or $1\frac{3}{4}$ miles shorter than the old aqueduct; and is 12 feet wide and 9 feet high where in rock and not lined, but only 10 feet wide where it is lined. The bottom is laid with concrete throughout, and it has a fall towards Glasgow of one foot in 5,500, or $11\frac{1}{2}$ inches per mile.

At several points along the line there are junctions between the old and the new aqueducts, where the flow of the water is regulated by means of stop-planks placed in recesses in the masonry; and at these places, access-chambers, ventilating shafts, overflow and discharge-valves are provided. The bridges, of which there are five, consist of an inner channel of concrete and outer walls of masonry, with an air space between to prevent the effects of variations of temperature upon the water channel. The pipes across the Endrick and Blane valleys will ultimately consist of four parallel lines, each 48 inches diameter. For the purpose of construction, the aqueduct was divided into seven sections, and the order in which these were executed was determined by the resistance which the water experienced in passing through the old aqueduct. The portions where there was the greatest resistance were first supplemented by corresponding portions of the new aqueduct.

The new Craigmaddie service reservoir, adjoining the Mugdock, will have a water surface of $86\frac{1}{4}$ acres, and will contain 700 million gallons of water, or a supply to the city for fourteen days at the rate of 50 million gallons per day. The two reservoirs together will contain sufficient water for twelve and a half days' supply at the rate of 100 million gallons per day. The inlet and outlet works are so arranged that either or both reservoirs may be used for the supply of the city. Considerable expense has been incurred in reaching a proper water-tight foundation for the puddle wall, the trench at one point having been carried to a depth of 193 feet below the original surface of the ground. It is expected that the whole of the works connected with the reservoir will be completed by next summer. The outlet works are similar to those of the Mugdock reservoir; and there will ultimately be four lines of 36-inch pipes leading to the

city, but two only are being laid down at present. The expenditure upon the new works up to 31st May 1895 has been £1,080,000.

The other works embraced in the act of 1885 include the raising of the level of the water in Loch Katrine 5 feet above its present top water-level, bringing its capacity up to 9,849 million gallons, which it is estimated will supply the city with 65 million gallons per day. The raising of the water-level in Loch Arklet 25 feet will add 10 million gallons per day to the supply. The first of these two works will be entered upon shortly. When additional water is wanted, it can be got from the adjoining valley of Loch Doine and Loch Voil, immediately north of the Teith valley. The whole of the works are under the superintendence of Mr. James M. Gale, Engineer to the Water Commissioners.

GLASGOW HYDRAULIC POWER SUPPLY, PUMPING STATION.

These works are situated in the north-east part of the city, at the corner of High Street and Rotten Row, near the Cathedral. The ground occupied is triangular in shape, and has been divided into two, forming a low-level and a high-level yard, one being 16 feet higher than the other. Between them is a retaining wall, varying in thickness from 2 to 6 feet. The main flue from the boilers passes through and along the back of the wall to the chimney shaft at the south-west boundary of the station; the shaft is 150 feet in height from the bottom of the flue, 14½ feet square at bottom, and 7½ feet across the flats of the octagonal part at top. The main buildings are of the castellated Scottish baronial style of architecture, and comprise engine-house, accumulator towers, boiler-house, workshops, store, offices, and space for workmen's dwellings; these take up the greater part of the lower yard adjoining High Street. The coal store and water-storage tanks, for supplying the water to the main pumps and condensers, form the roof of the boiler-house, and are on the same level as the upper yard; the entrance to the coal store and upper yard is from Rotten Row. The upper yard will be used for the storage of pipes.

The buildings have been designed for containing six sets of pumping engines and eight boilers, only half of which have at present been put in. The engines are of the marine type, inverted, direct-acting, triple-expansion, surface-condensing, and steam-jacketed. The cylinders are 15, 22, and 36 inches diameter, with 2 feet stroke. The three main pumps on each engine are single-acting, with rams $4\frac{1}{2}$ inches diameter and 2 feet stroke, and are driven direct from the engine cross-heads. The fly-wheel weighs about two tons. The condenser has a cooling surface of 530 square feet; and the quantity of water required for condensing is about equal to the quantity discharged through the power mains. Each engine pumps 150,000 gallons of water in 10 hours against a pressure of 1,120 lbs. per square inch, with steam of 150 lbs. per square inch. The boilers are Lancashire, made of mild-steel plates, 30 feet long and 7 feet diameter, with two flues $2\frac{3}{4}$ feet diameter in each. They are fitted with Vicars' mechanical stokers, to which the fuel is conveyed from the coal store above by means of steel-tube shoots. A Watmun automatic water-circulator is connected to each boiler; and Green's economisers for feed-water are placed in the main flue. The boilers were tested to 250 lbs. per square inch with hydraulic pressure, the working pressure being 150 lbs. per square inch. The stokers and economiser-scrapers are worked from shafting overhead, which can be driven either by a three-cylinder hydraulic-engine or by a small steam donkey-pump engine fixed in the boiler house. There is also provided a three-cylinder hydraulic engine to drive the machinery in the workshops, a 20-cwt. movable hydraulic crane on rails, for handling pipes in the upper yard, and a 20-cwt. direct-acting hydraulic lift from the lower to the upper yard. There are two accumulators, having cast-iron cylinders and rams 18 inches diameter and 23 feet stroke, with base plates 7 feet diameter and weight cases $11\frac{1}{4}$ feet outside diameter by 22 feet deep, suspended from the cross-heads on the top of the rams by strong steel sling-bolts. The accumulators are loaded with iron-stone slag to give a pressure of 1,120 lbs. per square inch, the minimum pressure guaranteed being 1,000 lbs. per square inch.

As at present arranged, about ten miles of piping will be laid to supply the central part of the City between High Street on the east, Cranstonhill on the west, Sauchiehall Street on the north, and the north side of the river Clyde on the south. About six miles of pipes have already been laid and put under pressure. Although not complete, the works were formerly inaugurated by the Lord Provost, Magistrates, and Members of the Town Council on 30th May 1895. A number of machines are already connected, and applications have been made for supply to others. The works were designed by Messrs. Ellington and Woodall, London, and carried out under the superintendence of Mr. James M. Gale, Engineer to the Water Commissioners. [See also page 353.]

SEWAGE PURIFICATION WORKS, DALMARNOCK.

These works, erected by the Police Commissioners, were opened on 2nd May 1894, and serve the eastern district of the city. The main sewer $7\frac{1}{2}$ feet diameter is brought down the centre of Swanston Street, and led into the entrance chamber, which is 17 feet long by 9 feet wide and 16 feet 1 inch deep, and is situated at the north-west corner of the precipitation tanks. On the east side, in front of three 4-feet penstocks, is a wrought-iron grid to catch heavy floating matter. The sewage is taken thence into the machinery building by three 4-feet by 4-feet invert channels, placed underneath the precipitation tanks and aerating beds, to the west side of the catchpits, where it has to pass through three 4-feet rotary screens of cast-steel, with bars $\frac{5}{8}$ inch apart. It then flows into the 5-feet feed channels on the west side of the catchpits. Lifting plates 4 feet by 6 inches are securely attached at intervals of 4 feet to the rotary screens for the purpose of taking up all floating matter, and depositing it into a wrought-iron trough placed in front at a depth of $10\frac{1}{2}$ feet below the floor line. The rubbish here collected is passed into a square wrought-iron self-tipping bucket, which is daily emptied into the destructor furnace. The screens work at an angle of 45°, and make 14 revolutions a minute.

The sewage flows from the 5-feet channel into two catchpits, each 47 feet 10 inches long by 20 feet broad. Three V shaped troughs run along the bottom of each catchpit, the bottom of the trough being 28½ feet below the floor line. A screw conveyor, making 4½ revolutions a minute, pushes the solid matter forwards to the elevator trough, the bottom of which is 33½ feet below floor line; and it is raised by the elevator buckets into a railway wagon on the floor level. The sewage free of heavy matter then flows from the catchpits into a 10-feet channel on the east side, leading to the pump well, which is 31 feet 1 inch below floor line.

The suction pipes from the centrifugal pumps are led down to within 15 inches of the bottom. The water is raised through these into a 3¾ feet cast-iron pipe placed against the south wall of the pump room, through which it flows into the mixing pit, where the chemicals are introduced. There are two 18-inch and two 15-inch pumps, with a total of 350 horse-power, capable of raising 1¼ million gallons per hour. Two 6-inch pulley-pumps on the east side of the pump room discharge the sewage water into lime-mixers over the sludge tank. This water is used for making milk of lime, and for dissolving the sulphate of alumina. The pulley pumps are driven from the main line of shafting, which is worked from the engine room, where there are two pairs of compound condensing engines, each 120 horse-power. The sewage water is used for the condensers; and these engines also drive a dynamo, which supplies all the lighting for the works. The mixing pit, 10 feet square by 8 feet deep, is divided down the middle by a tongue going down to within 3½ feet of the bottom; and the sewage mixed with the chemicals has to pass under the tongue into an outlet channel, 8 feet wide by 3½ feet deep, which leads to the feed channels of the precipitation tanks.

The sludge from the precipitation tanks is brought into the works by a 6½ feet main channel, falling 3 inches in 100 feet from the tanks. In front of each section of these tanks is a channel for the sludge to run into a tank under the mixing rooms. This tank is 80 feet long, 46 feet wide, and 21 feet below the floor line at the west end and 23 feet at the east end. In the north-east corner is a low-pressure sludge-ram, capable of holding

1,800 gallons, through which the sludge is raised by compressed air into two mixers in the lime room. Here hot lime is added to facilitate the pressing.

In the low floor of the sludge-receiving room are four high-pressure rams, each holding 900 gallons. The sludge runs from the mixers by gravitation through a 6-inch cast-iron pipe into these rams, whence it is raised by compressed air at 100 lbs. pressure per square inch into the presses. When the air has blown the sludge from the high-pressure rams, it is transferred into the large low-pressure ram in the north-east corner of the sludge tank, thereby effecting a saving of 80 per cent. of compressed air, by raising sufficient sludge into the mixers for recharging the high-pressure rams again. The compressed air is supplied by two high-pressure engines to the north of the rams.

In the press room on the top floor are seven sludge-presses, each when charged holding 25 cwts. of pressed sludge-cake, which is dropped through shoots in the floor into railway wagons underneath. The sludge, street sweepings, and ashpit ashes are mixed together and sold for manure. On this floor is also a large cast-iron sludge-tank, into which crude sludge can be raised, for the purpose of mixing with very dry ashes without putting it through the presses.

In the boiler shed are six Lancashire boilers, 28 feet long by 7 feet diameter, working at a pressure of 100 lbs. per square inch. The fuel used is the coke from the filtration beds, when it has become too dirty for filtering any longer. At the north end of the shed is a Babcock and Wilcox economiser, through which the feed-water is pumped into the boilers at 200° ; and north of the engine-room is a workshop for repairs.

In each section of the works, eastern and western, there are twelve precipitation tanks, each holding 81,000 gallons; they are worked on the intermittent system; and each can be charged in seven minutes. Precipitation takes place in forty-five minutes; then floating arms are lowered to draw off the clearer water, which passes across aerating beds. These tanks can be worked on the continuous system, which however has the disadvantage of allowing the sludge to accumulate, and the effluent can never be so clear;

whereas by the intermittent plan, sludge cake can be formed within five hours after the sludge has left the main sewer.

The filtering beds are twenty downward coke filters, each 40 feet long, 10 feet wide, and $3\frac{1}{2}$ feet deep, through which the water passes and rises in a 3-feet open channel. It again passes down through forty sand filters, each 40 feet by 38 feet and $2\frac{1}{4}$ feet deep. When the sand becomes dirty on the top, it is washed and used over and over again. Finally the effluent water passes into the river Clyde. The works at present constructed can deal with ten million gallons of sewage a day, or about one-fifth of that from the entire city; and they can be extended to treat twice the quantity. The buildings, tanks, and filtering beds cover 19 acres, and 9 acres more remain available. The land cost £38,000, and the buildings, tanks, and machinery £67,000. The manager is Mr. Thomas Melvin. The number of men employed is fifty, of whom the majority are on eight-hour shifts, as the work has to go on continuously.

CALEDONIAN RAILWAY LOCOMOTIVE WORKS, ST. ROLLOX.

These works occupy about 23 acres, the buildings alone covering about 12 acres. They were entirely reconstructed about ten years ago, for building and repairing all descriptions of railway rolling stock, care being taken to minimise manual labour in every detail.

The crude metal and rough timber enter the works at opposite sides, and passing straight on through the various processes of modelling and finishing, meet in the erecting shops, to form locomotives, carriages, and wagons. The machinery and tools are all of the newest and most approved kind. In the foundry are a number of moulding machines, one of which is capable of moulding 250 bushes for axle-boxes per day; they were constructed in the works, and are worked and cleaned by pressure of air supplied by a Westinghouse pump.

The locomotive erecting shop is capable of holding 80 engines and 15 tenders, and is fitted with six 30-ton overhead cranes, driven by rope gearing. In the wheel shop are two 5-ton overhead travellers; and a cylinder borer, which bores the stuffing-boxes for piston-rod and valve-spindle at the same setting and time. The lathes are so arranged that they can be run at mean speed, cones being done away with; and each is fed by a small hydraulic crane. The tools are driven from the main shafting, resulting not only in great saving of time, but in keeping each tool at regular work all the year round. The slowest rate of cutting in wheel-turning is about 19 feet a minute. The shafting is of the roll kind, fitted with spherical bearings. Another feature is a frame slotter, which slots six engine-frames at once; it has a 34 feet bed with 4 feet space between uprights, 13 inches stroke, and four heads, and was made by Messrs. Smith, Beacock, and Tannett, Leeds.

In the turning, machine, and fitting shop the tools are adapted to the lighter nature of the work. Amongst them are bush-bossing machines, by which one man can turn out on an average 280 bushes a day; two American turret or capstan lathes containing half-a-dozen chucks for special operations; and brass-milling machines designed and built in the works. Link belting and rope gearing are used here.

The smithy and forge contain a hundred fires, blown by a Root's blower of the largest size, nineteen steam-hammers ranging from 15 cwts. to 3 tons, heavy shears cutting up to 6 inches square, and machines for nut, bolt, and rivet making. Hydraulic power is used all over the works at pressures of from 800 lbs. up to 1,000 tons per square inch. A machine for bending wagon-wheel spokes is of ingenious construction, and admirably adapted for the purpose.

The rolling stock comprises 713 engines, 1,830 carriages, and 53,480 wagons. The gross number of engines built, rebuilt, renewed, and repaired annually is over 900, carriages over 6,000, and wagons over 63,000. The locomotive superintendent is Mr. John F. M'Intosh. Upwards of 2,500 men are employed in the works, and nearly an equal number in the running department.

MESSRS. DÜBS AND CO., GLASGOW LOCOMOTIVE WORKS.

These works, which were built by the late Mr. Henry Dübs in 1863, are situated in the south-eastern district of the city. They have a frontage of 1,300 feet to Aitkenhead Road, and a frontage of almost equal extent to the main line of the Caledonian Railway, with which they are connected by sidings. Even when first built they were of considerable magnitude, covering about $8\frac{1}{2}$ acres; and they were carefully designed by Mr. Dübs with a view to the extensions since made, which have increased their area to between 11 and 12 acres. When working under pressure they are capable of turning out nearly 200 locomotives a year.

The offices are of unusual magnitude, and full provision has been made for the clerical and drawing-office staff. All the departments are lighted by electricity. The drawing-office is about 120 feet long by about 40 feet broad, and has separate desks or tables ranged on each side, while along the centre runs a broad counter fitted with drawers containing the original drawings of the engines and tenders which are in progress in the works. At the extreme end is a highly finished slide-valve motion metal-frame, where the valve-gear of all classes of engines is tried, the proper angle for eccentric-pulleys and the length of eccentric-rods and valve-rods &c. are ascertained, and the valves are accurately set. Above the drawing-office is the tracing department, where a number of young ladies are engaged in making tracings from the original drawings for use in the shops. There is also on this floor a well-equipped photographing room, where prints are taken off the drawings.

Immediately under the drawing-office on the ground floor is the locomotive store, where all the materials used are kept; forgings from the smithy, and iron and brass castings from the foundry are sent here, weighed by the store keeper, and put on shelves till wanted in the machine-shop; whence they are returned to the store, and kept until required in the erecting shop.

In the forge the largest steam-hammer is principally used for stamping wrought-iron wheel-cranks, balance weights, wrought-iron axle-boxes, &c.; and under the same hammer all coupling and connecting-rods and other heavy details are forged. There are a number of smaller hammers for lighter work; and a special hammer having its standards wide enough apart for bossing the largest sizes of wrought-iron wheels. The wheels are heated in a specially prepared fire to heat the centre only, while the washers to form the boss are heated in an adjoining furnace to a soft welding heat, and are then welded, one on each side, under the steam-hammer. In the smithy are the usual small hammers, a Ryder forging-machine, and two pairs of steam-strikers, where bolts, washers, nuts, and tube-ferrules are made.

In the boiler shop are two 10-ton travelling cranes, and two hydraulic jib-cranes for serving the stationary hydraulic riveting machines. The largest riveter has a gap of 12 feet, and is capable of riveting up an entire locomotive-boiler and fire-box. There is also a set of 10-foot vertical-rolls for bending the barrel plates of boilers; and immediately adjoining is a large boiler-shell drilling-machine, having six radial arms and drilling heads, three on each side, specially designed to drill all holes in position, thus doing away with the necessity of the holes being rimered when plates are drilled separately. A number of tacking holes are drilled while putting the boiler together, then temporary brackets with pivot ends are attached to each end, and the boiler is placed in bearings on a trolly and run under the machine, and all the holes in the upper half are drilled; the boiler is then turned half-way round, and the other half drilled, the whole boiler being thus drilled complete with only one shifting (Proceedings 1894, page 521). There is also a quadruple fire-box side-tapping machine, with which the four sides of a locomotive fire-box are tapped at one time, a copious supply of lubricant under pressure being supplied to keep the taps cool. There are also portable hydraulic-riveting machines, and a special machine for riveting fire-doors and fire-box foundation-rings. Attached to this department is a large hydraulic flanging press, for which the power is supplied from an accumulator at a pressure of 1,500 lbs. per square inch.

In the foundry is a 15-ton travelling crane, and two 3-ton hydraulic jib-cranes; and two cupolas, each capable of melting 9 tons of metal per hour. There are also three large core-drying stoves. Outside is a 5-ton hydraulic crane, round which the moulding boxes are laid when not in use; when wanted they are lifted upon a trolly wagon by the crane, and run into the foundry.

In the erecting-shop are three 20-ton travelling cranes, worked by rope and friction gear, and running the whole length of the shop. In the next bay, which is used as a tender and boiler-mounting shop, there is a portable drilling machine for drilling the holes for studs, &c., for fixing the boiler mountings. A slide is fixed on the side of the boiler, to which is attached an arm with drilling-head worked by rope gear, whereby all the holes in the boiler can be drilled. Under the same roof is the machine shop, in which the first bay is wholly occupied by machines and lathes for dealing with the frame-plates and wheels. The machines for planing, drilling, and slotting frames are all of Whitworth make, and the great bulk of the tools in this department are from the same firm. There is here a quartering machine, designed by the late Mr. Dübs, and made in the works; in this the holes in the crank bosses of the pair of wheels for receiving the crank-pins are bored to the exact throw of crank wanted, while the crank-pins when in the wheels can also be trued up in the machine, making them exactly at right angles to one another. Adjoining are two large Whitworth lathes, and a facing lathe for boring tires &c., having a chuck 11 feet diameter; and a hydraulic wheel-press worked at a pressure of about 10 tons per inch of diameter of axle. In the next bay are three mills for boring and facing locomotive cylinders; special axle-lathes, having combined slide-rests for turning both ends of the axle at one time; a number of planing machines with Whitworth reversible tool-holders; and a lapping machine designed by the late Mr. Dübs, on which case-hardened slide-bars, wrought-iron case-hardened axle-boxes, and other flat parts are lapped up to a true surface. There are also heavy planing machines for planing cylinders, cast-iron foot-plates, and similar work. In the next bay the machines and lathes are of a lighter kind, and are used for machining and turning valve-motion

details, pins, &c. On one of the shaping machines a special head is fixed for circular shaping, also designed by the late Mr. Dübs, having a ball-joint connecting-rod, whereby the fillets of the ends of coupling and connecting-rods can be shaped to the radius of the end of the rod. In the next bay is the grinding and polishing shop, where all parts of the valve-motion are polished on emery wheels after being case-hardened. Here also are the tables for marking off the work for the machines; and the brass finishing shop, in which are also machines for milling flats and edges of coupling and connecting-rods; and a 30-ton Buckton testing machine.

In the yard is a 4-ton steam-crane, within the range of which is a gas furnace, where the tires are heated and expanded for shrinking upon the wheels. At work in the yard is a combined locomotive engine and crane, designed by the late Mr. Dübs and made in the works; large numbers have been made in various sizes, the heaviest for lifting and handling up to 7 tons. All the operations of slewing, hoisting, and working the engine are manipulated by the driver from the foot-plate. The number of men employed is at present over 1,700.

MESSRS. NEILSON AND CO., HYDE PARK LOCOMOTIVE WORKS, SPRINGBURN.

This firm was founded in 1837. The works were originally situated in Hyde Park Street, close to the harbour; and were removed in 1862 to their present situation in Springburn. At that time the partners were the late Mr. W. Montgomerie Neilson and Mr. Henry Dübs; and when at the end of 1863 the latter withdrew from the firm to establish works of his own, Mr. James Reid became a partner, and continued in the management till the retirement of Mr. Neilson in 1878. From that time till his death in 1894, Mr. Reid remained at the head of the business, being sole proprietor till 1st January 1893, when his four sons became his partners. Since the removal to Springburn the business has steadily grown. In 1865 about 1,000 men were employed, and the output was 82 engines; the present establishment when fully equipped employs

over 2,500 men, and turns out more than 200 main-line engines a year; it is thus the largest of the kind in Great Britain.

The new offices built in 1887, comprising the commercial and drawing departments, are the latest addition to the works, and are a model of convenience. The other various departments are arranged with a view to the regular sequence of work being followed throughout. The pattern shop leads to the brass and iron foundries and coppersmiths' shop, the template shop, and the boiler and tender shops, parallel to which are the smithy and forge. The boiler shop contains a hydraulic flanging press for locomotive plates, special machines for drilling boilers together and apart, hydraulic riveter, &c. In another large block of buildings, opposite to the boiler shop and smithy, and parallel to one another, are the grinding, finishing, turning, machine, wheel and frame, and boiler-mounting shops, finishing with the erecting shop, the focus of the work from all the other departments. A spacious steaming shed serves to relieve the erecting shop after the engines have been put together, and enables work to be stored if there is any delay between completion and shipment. The packing and painting shops complete the works. The locomotives made here are of all classes, and examples of them are to be found on almost all railways. The total output to the present time amounts to nearly 5,000 engines, which, if placed end to end, would extend over thirty miles.

NORTH BRITISH RAILWAY WORKS, COWLAIRS.

These works occupy about 25 acres, and are used for building and repairing railway plant. Entering from Keppochhill Road is the timber yard where there is a 10-ton steam travelling-crane, having a span of 20 yards, and a longitudinal travel of 72 yards. The wagons run beneath, so that loading and unloading can be done with the utmost facility. On one side of the yard is the wood-drying shed; and close by is the fire station, where two manual fire-engines and all necessary fire-extinguishing appliances are kept. Across the yard is the foundry, where all iron castings are made for the

locomotive department, and a large quantity of special castings for the permanent way. In the same building are the pattern shop and the brass foundry. The general store is a few yards distant, and the wheel-turning shop is close by. Alongside is the carriage and wagon fitting shop. Across the passage is the carriage wood-wheel making shop, where the wheels are finished and balanced. The forge and smithy are opposite. In this department are seventeen steam-hammers ranging from 5 tons to 5 cwts., seventy smiths' fires, and seven forgers' furnaces. Above the latter are placed horizontal boilers, and the waste heat and gases are utilised by being passed through them. A large hydraulic stamping press and a number of small hydraulic machines are also here.

On the way from the smithy to the principal machine-shop are the spring-smiths' and grinding shops. The machine-shop is fitted with all necessary appliances for machining the rough material before it is passed on to the fitting and erecting departments; the motive power for working the machinery is obtained from a double-acting horizontal engine. Adjoining is the boiler shop, which contains straightening and bending rolls, planing, punching, shearing, and drilling machines, hydraulic riveters, and a plate-flanging machine. In another part of this building the tender tanks are made. The running shed comes next, and in front of this are kept the accident crane, tool van, and snow ploughs.

The erecting shop is built in three bays with three lines of rails and two 30-ton overhead power travelling-cranes in each bay. Sixty engines and twelve tenders can be dealt with at once in this shop. Conveniently placed in the yard outside is the weighing shed, where all engines and tenders on leaving the erecting shop are weighed, and the weight on each wheel accurately recorded. Adjoining the erecting shop is the brake-fitting shop. Separated from the erecting shop by a line of rails is the wagon shop, where wagons are built and repaired. Under the same roof is the saw mill, which is fitted with all kinds of modern wood-working machinery. The carriage shop is one long shop divided, one part being used for building carriages, the other for repairing. The paint shop is close by, where engines and carriages are painted; paints are ground by

machinery and prepared for use in the paint store, which is at the end of the shop. The cabinet shop comes next, in which all carriage internal fittings are finished. In the trimming shop upstairs all upholstery work is prepared for the carriages, and the necessary belting for the works. The tin and coppersmiths' shops are close to the principal machine-shop.

The offices are also in this part of the works close to the railway, and comprise the locomotive superintendent's, drawing, running, general, and works-manager's offices. Throughout the works narrow-gauge tramways are laid, over which trolleys convey material between the various departments. The rolling stock consists of 701 engines, 2,755 coaching vehicles, and 51,666 wagons and trucks. The locomotive, carriage, and wagon superintendent is Mr. Matthew Holmes. The number of men employed is 2,112.

MESSRS. SHARP, STEWART, AND CO., ATLAS WORKS, SPRINGBURN.

These works, situated close to the Barnhill station of the Glasgow City Union Railway, were originally built by the Clyde Locomotive Co. in 1884, and were occupied by them until their amalgamation with Messrs. Sharp, Stewart, and Co., who then removed their locomotive and machine-tool business from Manchester to Springburn. They have since been considerably extended.

The offices are situated near the eastern angle of the ground; and extending from them round the angle and along the north-east side come the pattern store, pattern and joiners' shops, brass foundry, iron foundry, forge and smithy. The iron foundry contains overhead rope travelling-crane and hydraulic cranes. Beyond the forge, in the northern angle, is a vacant piece of ground, available for future extension. Leading from the smithy and foundry is a narrow-gauge tramway, passing through the stores, which stretch parallel with the smithy towards the centre of the ground; it is so arranged that the rough material can be brought into the drawing-in department, and thence into the main machinery building. Under the same roof as

the drawing-in shop are the brass-finishing and grinding shops; and immediately adjoining these is the main building, consisting of six bays, and occupying the whole of the south-western portion of the works.

The first two bays are shorter than the others, and form, with the first of the long bays, the fitting shop and light-tool shop. The other three long bays form the heavy-tool shop, the boiler-mounting and frame-fitting shop, and the erecting shop. The total width of the six bays is 280 feet, and the average length of the long bays is about 400 feet. The narrow-gauge tramway traverses the different departments; and the larger bays are served by rope-driven overhead-cranes, of which there are two in the erecting shop, and by a travelling jib-crane. Hydraulic jib-cranes are also placed in other convenient positions throughout the works, especially in the erecting shop and cylinder-fitting shop.

At the other side of the yard, opposite the end of the erecting shop, is the paint and packing shop, occupying the southern angle; and in the middle of the south-eastern side is the boiler and tender shop, consisting of four bays, 150 feet long and together 160 feet wide. This shop is fitted up with the most approved modern machinery, including special drilling machines and hydraulic riveters. Each of the two principal bays contains an overhead rope travelling-crane, and various hydraulic cranes are placed in convenient positions. Parallel with the boiler shop, and lying towards the centre of the works, is the furnace and flanging shed, with the necessary plate-furnaces and a hydraulic flanging press. Parallel again with this are the main boiler-house, case-hardening furnaces, annealing furnace, and coppersmiths' shop.

The power throughout is supplied by special vertical wall-engines placed outside the buildings, one at the end of each bay containing machinery. The works are lighted throughout by gas, special lamps being employed in the erecting and boiler shops.

The machine-tool shop lies on the north-western side of the works, close to the stores and main machinery building. It consists of three bays, a large one in the middle with a small one on either side. The centre bay is served by a 25-ton overhead travelling-

crane, and at one side is a 5-ton rope travelling jib-crane. The shop is arranged for dealing with all classes of work, up to the heaviest tools required in connection with marine and ordnance work.

The locomotive department is capable of turning out 150 engines a year. The number of men employed is about 1,800.

MESSRS. ALLEY AND MACLELLAN, SENTINEL WORKS, POLMADIE ROAD.

These works consist of a foundry, engineering shops, and shipbuilding yard. All the ships built here are erected in the yard, and are then taken to pieces for erection abroad. The special work produced comprises steering gears, high-speed engines for electric lighting, warping capstans, ash and coal hoists, marine engines up to 1,000 I.H.P., feed-water filtering apparatus, light-draught steamers and their machinery, valves for water works, and valves and fittings for steam boilers. The number of men employed is from 600 to 800.

MESSRS. BARCLAY, CURLE, AND CO., SHIPBUILDING YARD AND ENGINEERING WORKS.

This firm of shipbuilders and engineers is the oldest established on the upper reaches of the Clyde, having been founded by Mr. R. Barclay at Finnieston in 1818. With the extension of their business in 1855 they removed part of their works to the present ship-yard of Clydeholm at Whiteinch; and in 1874, owing to the Glasgow dock extension necessitating their removal from Stobcross, the Clydeholm yard was increased and the whole of the shipbuilding plant removed to the present works. These are commodious and complete in every respect for the efficient and speedy construction of vessels of all sizes and descriptions. They occupy an area of over 13 acres, with about 1,000 feet of river frontage; and comprise eight launching berths, capable of laying down vessels up to 550 feet long. The buildings are all comparatively modern; the saw mill and

joiners' shop with mould loft are perhaps the most commodious of the kind on the Clyde; while the smithy is 200 feet long, including finishing shop and all necessary appliances for heavy forging work. Besides work for the government, the firm have constructed a number of ocean passenger liners, cargo steamers, steam tugs, and steam yachts; and have long been noted for the beautiful models of their sailing ships, and for the success of the light-draught fast passenger paddle-steamers built by them. The latest vessel is the 404th, and the work at present in hand comprises several cargo steamers, one sailing vessel, and a large steamer of 8,000 tons dead-weight, constructed for carrying frozen meat in cool chambers from New Zealand to this country.

Previous to 1857 the works were only for shipbuilding; but in that year the firm commenced to make engines, not only for ships built by themselves, but for those constructed by others. From 1857 to 1861 the engineering department was carried on in a portion of the building yard at Clydeholm; but in the latter year pressure of work caused new and much larger premises to be secured at Finnieston Quay, where many marine engines of all kinds and sizes were made. In 1894, owing to the construction of the Harbour Tunnel, a removal took place to the present sites, the engine works to 36 Finnieston Street, and the boiler works to 90 Kelvinhaugh Street.

Entering at Finnieston Street, on the right are the general store, counting house, and drawing offices. On the left is the erecting shop, 160 feet long by 60 feet wide, with a 40-ton overhead travelling-crane; the roof is high enough to allow for the erection of long-stroke vertical engines; on the south side is a gallery 15 feet wide, running all the length; this being furnished with vices and benches forms an excellent and well-lighted finishing shop. Further on are the main and auxiliary smiths' shops, with air-furnace, steam-hammers, and other accessories. Right across the yard in front of the entrance are the large turning and machine shops, together forming a building 260 feet long, which has three spans in width, one 32, one 40, and one 25 feet wide. Each of these divisions is supplied with overhead travelling-cranes, so that every

portion of floor space can be utilized. Both large and small machines of the most modern kind have been introduced, in order that engines of all sizes, for screw or paddle, pinnace or ironclad, may be economically constructed.

The boiler works are situated seven minutes' walk from the engine works. They have a street frontage of 180 feet and extend inwards 245 feet, with cast-iron pillars supporting the roofs in the interior. On entering, to the left are the offices, rolling, welding, and smiths' shops; also large plate-furnace and heavy riveting-machine shop, which is 46 feet wide and is fitted with overhead travelling-crane. Further on is the flanging shop, with all the necessary hydraulic appliances for flanging boiler-ends, furnace mouths, tube plates, and combustion-chamber plates. To the right are two shops, each having a span of 46 feet, in which the boiler plates are planed, drilled, riveted, and erected. Here also the machines are numerous and of the most modern kind, and capable of turning out a large number of boilers annually.

Behind the boiler works are the ship repairing works, which are entered from Kelvinhaugh Road. These premises are well arranged, having been recently built to meet the requirements of the repairing business. All kinds of ship work are done here, iron, smith's, carpentry, and joiner work; spars and masts, either of iron, steel, or wood, are constantly under construction; and owing to the works being situated close to the Govan graving docks, many vessels of all sizes and nationalities are docked and painted by the firm. In busy times about 2,000 men are employed in the shipbuilding and engineering departments together.

MESSRS. JAMES DUNLOP AND CO., CLYDE IRON WORKS, TOLLCROSS.

These are almost the oldest iron works in Scotland, and are famous in connection with the researches and discoveries of David Mushet and James Beaumont Neilson (Proceedings 1859, pages 98–108; 1860, pages 65–8). David Mushet joined the staff as accountant

in 1791; and during the time he remained in that position he made a large number of experiments in assaying, roasting, and cementing iron ores, decarbonising cast-iron for the production of steel and bar iron, and various other operations. He was the discoverer of the following processes: the preparation of steel from bar iron by a direct method, combining the iron with carbon; the beneficial effects of oxide of manganese on iron and steel; and the application of the hot-blast to anthracite coal in iron smelting. In 1799 he discovered titanium, upon which his son has founded the titanium process. When J. B. Neilson first proposed the hot-blast in 1825, the idea was ridiculed by almost all the ironmasters in Scotland, none of whom could be induced to try it on their furnaces, until at length he persuaded Mr. Charles McIntosh of Crossbasket and Mr. Colin Dunlop of these works to allow a trial of his process to be made on one of their furnaces. After experimenting here for some years, the idea was matured into a definite and practical form, and its value for iron-making was at once admitted. At present there are four blast-furnaces in operation here; the brands of pig-iron made are "Clyde," "Monkland," and "Clyde Hematite." The furnaces receive blast from a blowing engine, with two steam-cylinders 50 inches diameter, and two air-cylinders 100 inches diameter by 9 feet stroke, connected by massive walking beams. There is also an auxiliary blast-engine of smaller dimensions, kept in reserve. Instead of the waste gases from the blast-furnaces being used at once as gaseous fuel, they are passed through ammonia apparatus, in which sulphate of ammonia, oils, tar, and pitch are produced. The gases are drawn through by four Root's exhausters; and after being washed, cooled, and deprived of their tar and ammoniacal products, are then passed on for utilization as fuel. A portion of the gas is used for raising steam in the boilers supplying the engine in connection with the hoists, blowers, and exhausters; while another portion is used in regenerative hot-blast stoves. The workshops comprise joiners', engineers', and blacksmiths' shops, and a foundry in which castings are produced both for use in the works and also for outside supply. The number of men employed is 300.

MESSRS. DAVID AND WILLIAM HENDERSON AND CO., SHIPBUILDING YARD AND ENGINEERING WORKS, PARTICK AND FINNIESTON.

The shipbuilding yard and engineering works are separated, the former being situated at Partick, and the latter higher up the river at Finnieston. The ship yard is one of the oldest on the river, and has in every way kept pace with the times. It was first occupied about 1840 by Messrs. Tod and McGregor, and from its slips were launched many of the finest vessels of their day, including the earlier steamers of the Peninsular and Oriental and Inman lines. The present firm took possession in 1873, and the establishment has gone on increasing, until at present the shipbuilding yard covers an area of about 25 acres. In the model room is a large collection of models, ranging from the vessels just mentioned down to modern steamers and sailing ships, and including those of the many famous racing yachts here built, among which are the "Thistle," "Britannia," and "Valkyrie." Each of the various buildings in the yard is devoted to the work of a separate department, including the saw mill, carpenters', joiners', smiths', plumbers', painters', tinsmiths', and riggers' shops, and the ironworking sheds. The yard is bounded on the east by the river Kelvin, where the vessels lie while they are being completed. At this part of the yard there is a hydraulic slip where vessels up to 1,000 tons are docked for painting and repairs. The main portion of this work is executed in the large graving dock situated in the middle of the yard, adjacent to all the principal departments. This dock is 500 feet long, and is capable of accommodating vessels of nearly 6,000 tons. Its proximity to the machines and other conveniences of a ship yard renders it very serviceable in the execution of extensive repairs.

The engineering works at Finnieston are extensive and convenient, being situated on the river side and immediately adjacent to the Clyde Trustees' 130-ton crane for shipping heavy machinery. Besides the engineering, smiths', pattern, and boiler shops, they contain an iron and brass foundry, and finishing shops, copper and

plumber shops, and a forge. The advantage of having all these departments under one control is great in connection with the extensive repairing work here executed. The number of men employed in the shipbuilding yard and the engineering works together is 3,200.

NEW HOWE MACHINE CO., BRIDGETON.

The buildings, which were originally erected by the Howe Sewing-Machine Co., cover an area of 6,500 square feet. The main building is five storeys high, and is equipped with machinery for the manufacture of cycles. On the ground floor are the tool shop, and press room with nine power-presses for punching and pressing from the sheet, the smithy with one 10-cwt. drop-hammer, seven at 3 cwts., and one 30-cwt. steam-hammer, and the various trimming machines for making drop forgings; this class of work is also done for other trades. On the ground floor is also the foundry, where castings are made in steel, cast-iron, cast-malleable, brass, and aluminium. Here also are the case-hardening, brazing, and enamelling shops. The power for the machine shops is derived from a pair of horizontal Corliss engines, having 24-inch cylinders and 4 feet stroke, and supplied with steam at 70 lbs. pressure per square inch from three Lancashire boilers. The plating shop is also on the ground floor, with plating vats for copper and nickel.

On the first and second floors are the frame and wheel builders, tire department, ornamenting room, and the buffing department for preparing the various parts for polishing and nickel plating. The third and fourth floors are utilised as machining shops, where the component parts are turned, bored, and milled, each part being done in jigs or fixtures to ensure perfect interchangeability. Chain and tooth wheels are cut by automatic milling-machines. On these floors are also monitors for making screws, studs, balls, &c., turret lathes for the manufacture of the larger parts from the bar, and machinery for turning out the chains. The stores for all finished and partly finished parts are on the third floor, whence they can conveniently be

despatched quickly to every portion of the factory. The works are capable of turning out 500 cycles a week, besides castings, forgings, and pressed work for all trades.

HYDE PARK FOUNDRY CO., FINNIESTON STREET.

This foundry was built more than fifty years ago, and is chiefly engaged in the manufacture of iron castings for marine engines up to the heaviest class. Here have been cast the cylinders and other heavy castings for the engines of many of the most celebrated steamers and war-ships. Among the latest are those for the engines of the "Terrible," "Jupiter," and "Mars," building at Clydebank and Birkenhead; and the low-pressure cylinders, 35 tons each, for the Queenborough and Flushing mail steamers building at the Fairfield Co.'s yard. The works cover over two acres, and when fully occupied employ about 400 men. The ground and buildings belong to the trustees of the late Mr. W. Montgomerie Neilson, who was senior partner of the firm until his death in 1889. The sole partner is now Mr. Alexander Wilson, and associated with him in the management are Mr. Thomas C. Campbell and Mr. Thomas Downie.

MESSRS. A. AND J. INGLIS, POINT HOUSE SHIP-YARD.

The engine works, known as Whitehall Foundry, situated between Warroch Street and Whitehall Street and having entrances in both, were established in 1847; the original workshop about 40 feet square is still in use. The principal machine-shop and fitting shop were added in 1862. About twenty years ago the boiler work was removed to Point House, where commodious new shops were erected; this was the first step towards the removal of the whole works to the neighbourhood of the ship-yard. The latter was opened in 1862, and since then has been extended, and most of the

workshops have been rebuilt. It is well equipped with modern ship-yard tools, and though small in extent is capable of turning out considerable tonnage. In 1867 a powerful slip-dock was added; and a large repairing business is carried on in the dock and at the wharves. The river Kelvin having been dredged at its mouth serves to berth large vessels. The yard has also railway communication with the North British and Caledonian lines. The number of men employed is about 2,000 in busy times.

MESSRS. MAVOR AND COULSON, ELECTRIC WORKS, BRIDGETON CROSS.

These works are entirely occupied in the production of dynamos, motors, and other electric apparatus for lighting and transmission of power. A special feature is the manufacture of appliances for concentric wiring, in which the whole of the conductors, switches, and other parts of the apparatus are throughout enclosed in a continuous metallic envelope. Another feature is the application of electricity to mining work. Special machinery has been designed, including a mining motor entirely enclosed in a steel shell, which affords perfect protection from gas, water, or falls from the roof of the mine, while, owing to the adoption of the Sayers plan, which allows of the lightest possible field-magnets being used, the whole is not heavier than open machines of the ordinary kind. About 100 men are employed, and owing to the increase of business new works are about to be built.

MESSRS. McDOWALL, STEVEN, AND CO., MILTON IRON WORKS.

These works were established in 1834 by Mr. John McDowall, who took into partnership in 1852 his nephew, Mr. Thomas Steven, and a few years later two other nephews. They occupy more than nine acres, which are almost covered with buildings, including stores,

forges, moulding shops, furnaces, ovens, grinding and finishing shops. A large business is done in sanitary, architectural, and general constructional iron-work: such as kitchen-ranges, of which alone the production in 1887 exceeded 10,000; rain-water pipes and connections, hot-water pipes, stable fittings, balcony railings, verandahs, and numerous other kinds of cast-iron work. Nearly 100 tons of metal are melted daily; and the number of men employed is about 1,000. A large amount of work is supplied to the War, India, and Prisons departments, the Admiralty, and other public bodies, and to many of the principal railways.

MESSRS. McONIE, HARVEY, AND CO., SCOTLAND STREET ENGINE WORKS.

These works are situated on the north and south sides of Scotland Street. The business was started by the late Sir William McOnie and his brother Mr. Peter McOnie in 1839 for the manufacture of sugar machinery; and in 1888 they were joined by Mr. Robert Harvey. The works on the north side of the street comprise erecting, machine, pattern, smiths', joiners' shops, brass foundry, and brass-finishing shop; also the offices and drawing office. There are four travelling-cranes driven by power from the main engine; two are in the erecting shop and two in the machine shop. On the south side is an additional and larger erecting shop, containing a powerful steam travelling-crane to lift 30 tons, also a large lathe, and planing and boring machines; the heavy sugar mills are erected here. At right angles to the erecting shop is the boiler shop, fitted with the necessary planing, boring, and flanging machinery, and with hydraulic power for cranes and riveting machines. The special machinery made in these works is for the production of sugar from the cane, and for sugar refining. The number of men employed is about 300.

MESSRS. MECHAN AND SONS, NEPTUNE WORKS, CRANSTONHILL.

These works are occupied chiefly in the construction of riveted steel pipes for water mains, sewerage, gas, and irrigation, water tanks, and general structural ironwork of a lighter kind. Hydraulic presses for stamping, forging, and flanging, play an important part in the operations. The largest horizontal milling-machine in Scotland is in use here; and the Haythorn water-tube boiler, constructed in the works, can be seen under steam. The number of men employed is 600.

MESSRS. MUIR AND HOUSTON, HARBOUR ENGINE WORKS, KINNING PARK.

These works were established in 1874, and at that time employed about 100 men; since then the number has increased to 350. The special work here produced consists of marine screw-engines of the smaller sizes from 20 to 300 nominal horse-power, and marine boilers up to the largest sizes.

MESSRS. NAPIER BROTHERS, WINDLASS ENGINE WORKS.

This firm occupies the premises in Hyde Park Street which were formerly the Hyde Park locomotive works of Messrs. Neilson and Co., who removed in 1862 to larger works at Springburn. The buildings were then modified for the manufacture of windlasses, capstans, and steering gear; and the numerous inventions developed under the mechanical skill of the late Messrs. Robert and John D. Napier have brought the works into the front rank for the production of this class of gear. The conduct of the business for some years past has been in the hands of Mr. T. M. Grant as managing director, and

Mr. Alexander Kelly who was partner with Messrs. Napier in the old firm. Having fitted the 3-inch cable gear on board the "Campania" and "Lucania," which is the largest of its kind in the world, they have now in hand the windlass and capstan gear for the "Powerful" and "Terrible" and nine other ships of the royal navy, besides work for the mercantile marine. Special machinery is used for cutting the teeth of large worm-wheels, spur and bevel wheels; and all the gears produced here are made with machine-cut wheels. Friction clutches, cat governors, silent winches, and travelling cranes also form part of the special work turned out. The number of men employed is 200.

MESSRS. PENMAN AND CO., CALEDONIAN IRON WORKS.

This firm commenced business about twenty-five years ago at works in Dalmarnock Road, which are now a branch establishment. The works visited are in Strathclyde Street, and were built in 1889, covering three acres of ground, and adjoining the Caledonian Railway, with which there is connection by a siding. Of the various sheds the principal one is 420 feet long and 120 feet wide, and is built in three bays. In the centre bay is a 35-ton travelling crane made by Messrs. Henry Wren and Co., Manchester. In the south bay are three 4-ton Tangye travelling cranes. Here the material goes through the preliminary stages in boiler construction. The machinery comprises two powerful hydraulic riveting machines for the shell plates; another riveting machine of special design for the flues; three boiler-shell drilling machines, one of which is so arranged that five holes in the butt-straps can be drilled at the same time; two turning machines for boring out the flue-holes, and turning up the outer edges of end plates and angle rings; a powerful set of bending rolls; a plate-edge planing machine capable of taking in plates 30 feet long by 6½ feet wide; two smaller machines for planing flue-plates and butt-straps; a corner-thinning machine; two powerful jib verticals; shearing machine, etc. Adjoining the

south bay are the machine shop and smithy, in which there are a flue-flanging machine, flue-drilling and turning machines, steam-hammers, etc. Electric lighting is adopted throughout these works, which are fitted with every appliance for turning out boilers of the highest class. When fully employed the average output is four Lancashire boilers per week. The number of hands is about 300.

MESSRS. DAVID ROWAN AND SON, MARINE ENGINE AND BOILER WORKS.

These works, which are situated in Elliot Street on the north side of the Clyde, were established by Mr. David Rowan in 1865. The trade carried on is the manufacture of marine engines and boilers of all types and sizes, together with the auxiliary machinery usual on board ship. The engine works proper consist of two bays running north and south. That on the west is the erecting shop, which is lighted from the roof and sides, and in it are placed the boring, drilling, tapping, and studding machines. The machine shop for heavy work occupies the ground floor of the east bay; and the first floor of the same wing serves as the machine shop for light work and the finishing shop, while the uppermost floor forms the pattern shop. Further east, and separated from the engine shop by the yard, is the smiths' shop, fitted with a forging furnace, eleven smiths' fires, and several steam-hammers. On the southern boundary of the works is the boiler shop, which consists of two bays running east and west. In one of these are placed the smiths' fires, flanging hammers, etc.; and all the internal parts of the boilers are here put together. In the other and outer bay, the work of rolling and drilling the shell-plates, and of riveting and finishing the boilers is carried out. The number of men employed is about 400.

MESSRS. HUGH SMITH AND CO., POSSIL ENGINE WORKS.

These works were established in 1875. The main shops extend to a length of about 230 feet by about 120 feet in width, and occupy the ground floor, being lighted from above. The travelling crane in the central building travels the entire length of the shop, covering an area of about 230 feet length by 40 feet width. The side shops, which are largely utilized for the lighter machine-tools, are also efficiently supplied with hydraulic and other cranes. The main engineering shops are fire-proof; and standing apart from these are the pattern store and offices, which are separate buildings. The work carried on is the manufacture of machine-tools for boilermakers, shipbuilders, bridge-builders, and iron works generally. A number of special machine-tools are made for flanging, bending, riveting plates, &c., in connection with shipbuilding and marine engineering; and hydraulic pumping-engines, accumulators, hydraulic machine-tools, and cranes, &c., are manufactured. The number of men employed is about 150.

MESSRS. STEVEN AND STRUTHERS, ANDERSTON BRASS FOUNDRY.

These works, situated in Elliot Street, were established thirty-five years ago, and have been enlarged from time to time, until now they are capable of turning out 65 tons of brass castings per month, and single castings up to 20 tons, especially castings in phosphor-bronze for propellers, large engine-castings, stems, sternposts, &c., for government cruisers. The machine-tools are specially adapted to the manufacture of all kinds of gun-metal fittings for engineers and boilermakers. Syrens, fog-signalling machinery, lanterns, revolving apparatus, and machinery for light-houses are also specialities of this firm. The number of men employed is about 160.

MESSRS. D. STEWART AND CO., LONDON ROAD IRON WORKS, BRIDGETON.

These works were founded in 1864 by the present chairman of the company, and are situated at the east end of Glasgow. They were at first employed chiefly in the manufacture of machinery for calico dyeing, printing, and bleaching; but soon the making of sugar machinery was begun, which now constitutes a large part of the output. In addition to these are made engines and boilers of all kinds and sizes for land use. The manufacture of electric lighting machinery has also recently been taken up. Within the last three years the works have been greatly enlarged and re-arranged, and now cover an extensive area. Upwards of 700 men are employed in the various departments, which comprise erecting, machine, and boiler shops, coppersmiths', brass-founders', iron-founders', and sheet-iron workers' shops.

MESSRS. JOHN URE AND SON, REGENT FLOUR MILLS, SANDYFORD.

These mills have been working for about five and a half years, and have a capacity of fully 100 tons a day. The motive power is supplied by a compound tandem engine with cylinders 22 inches and 40 inches diameter and 5 feet stroke, running at 45 revolutions per minute, with a flywheel $22\frac{1}{2}$ feet diameter grooved for nineteen ropes and weighing about 36 tons; it is assisted by two turbines 39 inches and 45 inches diameter, with a 9-feet fall. These are coupled together in such a way that, when all the machinery is in motion, the full water-power available is taken from the two turbines, and the engine takes up the rest of the load. When the mill proper or the engine has to be stopped for any reason, the turbines are available for driving the dynamos and the receiving and delivering machinery. The entire premises are lit by electricity, and are protected by automatic sprinklers, with the exception of the wheat and flour stores

and the engine and turbine houses, which are fire-proof. The mechanical arrangements are such that the wheat is not touched by hand from the time it is emptied out of the sacks from the lorries into hoppers in the courtyard, until it finds its way into other sacks ready to be weighed and sewed up as flour or offal in the flour store. Notwithstanding the quantity turned out per day, the number of hands employed throughout the entire mills is only seventeen on each shift, exclusive of the few required for receiving wheat, delivering flour, and cleaning sacks, &c.

MESSRS. GEORGE AND JAMES WEIR, HOLM FOUNDRY, CATHCART.

These works are situated on the river Cart at Cathcart, and were erected about nine years ago by the present proprietors. They comprise an iron foundry, brass foundry, pattern, machine, fitting, and erecting shops; also smithy and boiler shops, and adjuncts. They are devoted to the manufacture of feed-water heaters, feed pumps, evaporators, bilge pumps, and other marine auxiliary gear found in the leading mail and passenger steamships. The iron foundry contains two cupolas on the Herbertz principle, in which the blast is supplied by a steam jet. The machine shops are equipped with the most modern machine-tools, many of them specially designed; among these may be noted boring machines with facing slides on the spindles, and dividing tables. There are also a variety of facing and screw-cutting lathes by different makers, a side planer, five boring and tapping machines; while in the gallery of the machine shop are to be found some good examples of brass-finishers' turret-lathes, and several lathes for making studs from the bar. In the boiler shop is a special flanging machine for the round plates which form the ends of the evaporators. The works give employment to about 370 men, and are served throughout by travelling cranes and by a narrow-gauge shop-railway. A new building to include general and drawing offices is now in course of erection, the present premises being found too small for the growing requirements.

MESSRS. JAMES WHITE, INSTRUMENT FACTORY, CAMBRIDGE STREET.

This firm are manufacturers of optical, nautical, electrical, telegraphic, and surveying instruments, and give employment at present to over 200 operatives; the premises were enlarged some three years ago, when machinery of the latest improved kind was put in. Among the special work here turned out may be mentioned the Kelvin standard balances, well known to electrical engineers for their high accuracy and constancy; the inspectional instruments used on the switchboards of central or other electric-lighting stations; the recording instruments; and electric-supply meters. The Kelvin laboratory, which was added to the works on their extension, is fitted with all the instruments and appliances necessary for carrying on the standardizing department of the business. The Kelvin siphon recorders for submarine telegraphy are indispensable to the thorough equipment of cable stations; and the Kelvin navigational instruments, namely the mariner's compass and the sounding machine, have long been regarded as essential to the outfit of every ship, both in the naval and in the mercantile marine of the world. Here also are manufactured the Barr and Stroud range-finders. The manufacture of surveying instruments is a branch of long standing, in which, besides the home trade, a considerable business is done with the colonies.

MESSRS. ANDERSON AND LYALL, CLYDESIDE ENGINE AND BOILER WORKS, WHITEFIELD, GOVAN.

These works, situated near the public graving dock at Govan, were erected in 1879, and cover three sides of a square, occupying with the intervening yard space an area of about two acres. The various sheds and buildings are designed upon the best modern principles, and are equipped with mechanical appliances of the most

effective kind. The works are engaged principally in the construction of the larger sizes of marine boilers, and in repairing marine, land, and locomotive engines and boilers. Steam yachts, launches, barges, &c., are also built up to 100 feet in length. The number of men employed is about 200.

MESSRS. LINDSAY BURNET AND CO., MOORE PARK BOILER WORKS, GOVAN.

These works were established in 1883 by the late Mr. Lindsay Burnet, for the production of high-class boiler-work. They are fitted with special tools of modern description, suitable for the manufacture of multitubular boilers of all kinds, for use on land and on steamers, yachts, and launches; and also for the construction of feed-heaters and evaporators. There is a railway siding into the works from the Glasgow and Paisley Joint lines, with branches running into the shops. In 1887 Mr. Sinclair Couper became a partner in the firm, and now carries on the business since the death of Mr. Burnet early this year. The number of men employed is 140.

FAIRFIELD SHIPBUILDING AND ENGINEERING CO., GOVAN.

The commencement of this firm dates from 1834, when Mr. C. Randolph and Mr. R. S. Cunliff under the name of Randolph and Co. began business as millwrights, in works situated at Tradeston, then on the outskirts of Glasgow. This small concern has gradually developed into its present magnitude. The pay roll for the first year amounted to about £1,000, and is now about £400,000; the amount of business done then was equal to £2,663, and now the work completed is valued at about a million and a half sterling; the number of men now employed is about 5,000. Three years after the commencement Mr. John Elliot joined the firm, which was then called Randolph, Elliot and Co.; but in 1841 he retired.

In 1852 Mr. John Elder became a partner, the style being changed to Randolph, Elder and Co., and the construction of marine engines was then commenced. Two years later boiler-making was added, and in 1860 shipbuilding followed, less attention being given to millwrights' work. The first vessel constructed here was the Macgregor Laird, of 966 tons and 200 I.H.P., built for the African Royal Mail Co. The first four years' operations in shipbuilding were carried on in the yard now occupied by Messrs. Mackie and Thomson, Govan; but, owing to the increasing demands for space, the ground at Fairfield was acquired and laid out in 1864. The first vessels built at Fairfield were four blockade runners for Messrs. A. Collie and Co., of London. Mr. Elder's great idea was to add to the efficiency of the marine engine by reducing friction of the parts, increasing the power, and at the same time decreasing the consumption of fuel. He applied the compound principle of expanding the steam in two cylinders.

In 1868 Messrs. Randolph and Cunliff retired from the firm, leaving Mr. Elder sole proprietor. On his death in 1869 the firm was reconstructed, and in 1878 Mr. (afterwards Sir) William Pearce became sole proprietor. From that time a great advance was made; boiler pressures had increased from 60 lbs. to 90 lbs. per square inch, coal consumption was reduced by nearly 30 per cent., and speed materially increased. The transatlantic service has always been regarded as indicating the progress made in shipbuilding, and in this contest the Fairfield Works have taken a prominent part. From the building of the Guion liner "Arizona" in 1879, they have never for any length of time held any other than the first place in speed across the Atlantic. The other vessels built here for the same line were the "Alaska," and "Oregon," the latter making the outward run in 6 days 10 hours 9 minutes. Their latest vessels built for the Cunard line, the "Campania" and "Lucania," have now reduced the outward run to 5 days 7 hours 23 minutes and 5 days 8 hours 38 minutes homeward.

In 1885 Mr. Richard Barnwell became a partner with the late Sir William Pearce, and when the firm was transformed into a private company in 1886 he was appointed managing director; this

position he continues to hold in the public company which was formed in 1889. In addition to the Atlantic steamers built here, seventeen have been constructed for the North German Lloyd Co., of Bremen, and recently the twin-screw steamer "Normannia" for the Hamburg-American line. For the Orient line a number of splendid vessels have been built, including the "Orient," "Austral" and "Ormuz"; and most of those belonging to Sir Donald Currie's South African line, including the "Tantallon Castle," and the "Arundel Castle." Several notable paddle-steamers have been constructed for the Isle of Man service from Liverpool, for the Channel service from Dover to Calais, including the "Calais-Douvres," for the Newhaven and Dieppe, the Ardrossan and Belfast, and the Queenborough and Flushing routes. At present there are three paddle-boats in course of construction for the night service of this last route, which will be considerably accelerated. Several yachts have been built here, notably the "Livadia" for the Emperor Nicholas of Russia from designs by Admiral Popoff; and three for the late Sir William Pearce, each named "Lady Torfrida." The total number of vessels constructed from 1870 to the end of 1894 was 237, their gross tonnage in the twenty-five years being over half a million.

Amongst the work now in construction here are the hulls and machinery of two second-class wood-sheathed protected cruisers "Venus" and "Diana" for the royal navy, each 5,600 tons displacement and 9,600 I.H.P.; also hulls and machinery of three torpedo-boat destroyers, "Handy," "Hart," and "Hunter," the speed of which is to be 27 knots; hulls and machinery of three fast paddle-steamers for the night service of the Queenborough and Flushing route, two screw-steamers for the China trade of the Scottish Oriental Steamship Co., a large mail steamer for the Australian service, and extensive overhaul to two steamers.

The new offices extend along the Govan and Renfrew Road, 335 feet westward from the main entrance to the yard, and are in the Italian style. The drawing offices are on the first floor, that of the shipbuilding department having a large model-room at its east end. On the second floor is a large space with glass roof fitted up for

photographic purposes. At the east end of the buildings, adjoining the yard entrance, are the gate-house and weighing office, and the general entrance for clerks, whose offices are at the back of the building.

The most attractive room is the model-room, containing a number of interesting relics and many artistically finished models of the most notable vessels. Amongst the former are models of one or two frigates, the old Irish packets, and the turret ship "Hydra," built in 1871. The increase in size of ocean-going vessels is conspicuous in the models, which are nearly all made to $\frac{1}{4}$ inch scale, and have formed attractive features at various exhibitions, securing awards of merit, notably the Grand Prix of the Paris Exposition in 1889.

The works cover 50 acres, and comprise ship-yard, boiler works, engine works, and tidal basin. The shipbuilding department is under the management of Mr. Edmund Sharer; and, entering from the Govan Road, among the first places to attract attention are the large sheds in front of the slips, where all the principal work in connection with ship construction is done, excepting that carried on in the angle-iron smithy. The brass-finishing and founding shops and smithy are on the east boundary of the road; here castings are made up to 15 tons, including propellers of manganese bronze. In this foundry there are seven pit fires and two reverberatory furnaces of 10 and 5 tons capacity. Amongst the tools are the usual bending and levelling rolls, some of large size; a large power bending-machine for plates of flat keels, large angles, crease work, &c., punching and shearing presses, small rolls for mast making, plate-edge planing machines, and a machine for cutting elliptical holes. The engine that drives the shop is placed at one end, and here is also a Brush machine for supplying the eighteen 2,000 candle-power lamps used in lighting this shop and the ships in progress. In the machine-shed is a set of plate-bending rolls, constructed entirely of steel, the end frames and gearing being of cast steel and the rolls of forged steel, each drawn down from a single ingot; there are also four large lever double-punching and shearing machines, capable of punching $1\frac{1}{2}$-inch holes through $1\frac{1}{2}$-inch steel plates, and having a gap of 42 inches, so that plates up to 7 feet broad may have every hole punched in them. At present there are two planing machines,

and a third is shortly to be added, each capable of taking plates up to 36 feet long. A large hydraulic keel-plate bending machine has been supplied by Messrs. Hugh Smith and Co., Glasgow; all the working parts are of steel, and the weight, without engine, pumps, &c., is about 150 tons. The furnaces for bending the frames and plates, which are all of the Gorman kind, have been remodelled, and are now fired by gas-producing furnaces with most satisfactory results.

The engine works have a separate organisation from the yard, and are under the management of Mr. Andrew Laing. Recent improvements have been carried out by the extension and strengthening of the present wharf at the wet dock, and by the erection of a set of 130-ton sheerlegs in place of the former 80-ton sheers. A new boiler shop has been built, and large additions have been made to the machinery. The main building, which is about 300 feet square, is divided into four bays, with two-storey galleries for small tools between each. The bay to the extreme west forms the erecting shop for machinery; in the two adjoining bays the numerous parts for marine engines are produced; and the remaining bay is used for boiler work. Running parallel with the engine works at a distance of about 68 feet is a smithy, 300 feet long by 100 feet wide, having forty fires and eight steam-hammers, besides other tools of the usual kind. The intervening space provides additional room for boiler work. The new building is much higher than the old structure, so as to provide sufficient headroom for lifting the largest boiler above any other by means of the overhead crane. At a height of 43 feet 9 inches from the ground are longitudinal girders carried on columns, with rails for the 100-ton travelling crane.

Against the north gable of the boiler shop is a new flanging shed, containing Tweddell's hydraulic flanger supplied by Messrs. Fielding and Platt. This can work a flange 4 feet by 5 feet on a plate $1\frac{1}{2}$ inch thick, with 800 lbs. water pressure per square inch. The new machines in the engine works are so arranged that work entering from the flanging shed at the north end will pass in order to each successive machine, leaving the shop at the south end as a complete boiler, and passing thence on rails to the fitting-out basin. In this department is a horizontal flange-drilling and countersinking

machine, supplied by Messrs. Campbell and Hunter, which drills and countersinks the rivet holes of flanged plates at one setting, and can drill holes in furnace mouths from 2 feet 9 inches upwards. A 140-ton hydraulic riveter made here is used for shell-riveting, with a special 40-ton crane erected overhead, by which the plates are suspended with the axis of the boiler vertical. The vertical plate-bending rolls, by Messrs. Thomas Shanks and Co., Johnstone, are capable of bending cold steel plates $1\frac{1}{2}$ inch thick and $12\frac{1}{2}$ feet wide. Another special machine in the new shop is one for drilling rivet-holes inside furnace-mouths, by Messrs. G. and A. Harvey, Govan.

The engine shop contains along with other numerous tools a planing machine, which will admit 8 feet square under the cross-slide, and will take a cut 20 feet long. Each of the bays is served by a travelling crane, two of which are rope-driven and were made by Messrs. Sir W. G. Armstrong, Mitchell and Co.; the others were made on the works, and are driven by separate engines through steel wire-rope. There is a large treble-geared face-lathe, made in the works, which will turn 22 feet in diameter. Next to this is a large machine, also made in the works, for surfacing heavy work, and consisting of a large annular chuck $16\frac{1}{2}$ feet diameter, carrying sixty cutters near the outer edge; it is worked by spur gearing, and the chuck can be traversed 21 feet. In this part are also a large screw-cutting lathe $41\frac{1}{2}$ feet in length, a large slotting machine, and a large shaft-lathe. A novel tool for planing piston-rings and pistons is also used, which was designed by the late Mr. Randolph. In this shop are six galleries in two tiers, where the smaller machine-tools are placed; and on one of the top galleries brass finishing is done.

MESSRS. MACKIE AND THOMSON, GOVAN SHIPBUILDING YARD.

This yard is known as the Old Yard, having been the site where the firms of Messrs. Robert Napier and Sons, and Messrs. Randolph and Elder, now the Fairfield Shipbuilding and Engineering Co., successively began business. Among the early vessels built here by

Messrs. Napier was the "Simoon," the first iron vessel built for the Royal navy. Only a few months ago a disastrous fire destroyed the original buildings which had been occupied by these firms.

At the yard entrance are the offices and general store, and inside the yard on the right-hand side is a long range of buildings, in which are the plate and angle furnaces, frame shed, smiths' and engineers' shops, rivet store, saw mill, joiners' and pattern shops, moulding loft, riggers' store, and foreman's offices; while at the head of the yard are the shops containing the iron-working machinery.

The frame shed is 147 feet long by 50 feet broad, and is fitted with all the necessary appliances and machinery. The smiths' shop measures 117 feet long by 38 feet broad, and contains three steam-hammers and seventeen smiths' fires, being well adapted for turning out work expeditiously. In this building, but separated from the smiths' shop by an iron partition, is the engineers' shop, in which are placed the main engines that drive all the machinery in this part of the works, as well as the turning lathes, and the drilling and screw-cutting machines.

The next building, measuring 140 feet by 33½ feet, has just been rebuilt after the fire, and is three storeys in height; on the ground floor is the saw mill and wood-working machinery, while above are the joiners' and pattern-makers' shops, which are fitted with the best machinery, including circular and band saws, edge and surface-planing machines, moulding machines and large turning lathes. On the third storey is the moulding loft, extending the full length and breadth of the building. In the building containing the iron-working machinery are plate rolls, planing, drilling, shearing, and punching machines. On the west side of the yard are situated the spar sheds and timber racks.

The yard being situated on the south side of the Clyde, opposite the mouth of the river Kelvin, affords launching room for large vessels; and the railway station being opposite the main entrance, the cartage of materials is reduced to a minimum. The yard has been twice enlarged since the present firm entered on its occupancy, and now extends to about six acres; and it has frontage to the river for six building slips. For some considerable time before the last

enlargement the yard was busy with the construction of steam trawlers for the North Sea fishery, and had generally thirteen of those vessels on the stocks at one time; they were built three on end, and generally all three were launched on the same tide. The firm commenced business here in November 1888, and have built a hundred vessels, in addition to doing large and heavy repairs. The public graving docks being so near afford every facility for getting the latter class of work done cheaply and expeditiously. The number of men employed is about 600.

MESSRS. ROSS AND DUNCAN, WHITEFIELD WORKS, GOVAN.

This firm began business in 1876 in the Anderston district of Glasgow, and removed to their present premises twelve years ago. They are engaged principally in the construction of engines and boilers of the marine type for steamships and for land purposes, up to 1,500 indicated horse-power. The works cover an area of $1\frac{3}{4}$ acres. The principal line of workshops runs along one side of the yard for a length of 310 feet, and detached pattern and other shops are on the other side. The main erecting shops are among the loftiest on the Clyde, being 60 feet in height to the ridge-pole of the roof. The principal heavy tools are of modern make. Of three overhead travelling cranes the largest, made by Messrs. James Taylor and Co., Birkenhead, is capable of lifting 30 tons; it is driven by square shafting connected with the shop gearing. The hydraulic riveter was made by Messrs. Robert Harvey and Co., and is worked in connection with an accumulator, giving the advantages of combined blow and squeeze. Some of the best and most recent machine-tools were made by Messrs. J. Lang and Sons, Johnstone; and some special devices for saving labour and improving the quality of work have been designed by Mr. Robert Rankin, one of the partners. Steam for the shop engine is supplied by a double-furnace return-tube marine boiler, which has proved highly satisfactory for steady working and economy. The supply of air is heated by the waste

heat of the uptake, and is admitted to the furnaces as required, with a regulating arrangement under easy control of the fireman. In the management of the works some advance towards co-operative working has been made. The number of men employed is 250 when fairly busy.

MESSRS. ALEXANDER STEPHEN AND SONS, LINTHOUSE, GOVAN.

The old estate of Linthouse comprising 32 acres was acquired in 1870 by this firm, whose previous premises were at Kelvinhaugh; and it is devoted to their shipbuilding yard, engine and boiler shops, &c., and a range of dwelling-houses for workmen. A large overhead crane traverses the ship berths for the purpose of putting engines and boilers &c. into the vessels while still on the stocks. This forms a conspicuous feature from a distance.

The frontage to the river is sufficient for eleven slips. The old mansion of the estate has been retained and converted into offices. The shipbuilding shed is 500 feet long by 200 feet wide; adjoining it on one side are a forge and smithy, and on the other a three-storey building containing the boat and spar shed, joiners' shop, and moulding loft. Further back from the river is the boiler shop; and beyond this is the engine shop. These buildings each measure 220 feet long by 210 feet wide, and are connected by railway with the shipbuilding berths under the large crane. The works are well equipped with most efficient machines and tools. The output is large, and embraces all sorts and sizes of steamers and sailing ships. The number of men employed is about 2,000.

MESSRS. WILLIAM BAIRD AND CO., GARTSHERRIE IRON WORKS, COATBRIDGE.

These works were established in 1830, and have from time to time been extended with all modern improvements, for the manufacture of ordinary and hematite pig-iron. They also comprise apparatus for recovering the by-products from the blast-furnace gases. The number of men employed is 500.

SINGER MANUFACTURING CO., SEWING-MACHINE WORKS, KILBOWIE.

This company first established works in Love Loan, Glasgow, in 1867. The principal parts of the machines were supplied at that time from the head factory at Elizabethport, New Jersey, and were put together and tested in Love Loan for the European demand. Two years later, premises were taken in James Street, Bridgeton, of sufficient capacity to turn out 600 machines a week; but in two years' time these proved too small, and continual additions had to be made; part of the work had also to be done in Govan Street, and part at Bonnybridge, 18 miles from Glasgow. A weekly average of 5,150 machines having then been reached, it was decided to erect a factory at Kilbowie, 9 miles below Glasgow, large enough to contain all the scattered departments, and to allow of manufacturing 10,000 machines per week. A freehold property of 46 acres was purchased at Kilbowie-by-Clydebank, and the present factory erected. This production has already been reached, and extensive additions have had to be made to the works. The Forth and Clyde Canal runs past on one side, and the North British Railway on the other, giving excellent facilities for receiving and shipping, which will soon be increased by the completion of the Lanarkshire and Dunbartonshire Railway through Clydebank. Within the factory grounds are four miles of railway, connecting the various departments with the main line and the canal, and two shunting engines are constantly employed.

Power is furnished by a number of engines, giving collectively about 2,000 horse-power, for which the steam is generated by a number of Babcock and Wilcox tubular boilers, having a total capacity of about 2,350 horse-power. The use of automatic stokers in connection with the boilers has reduced the smoke to a minimum. Hydraulic power is also largely used for hoists, moulding machines, and various other manufacturing operations.

The main structure is fire-proof, and consists of two parallel buildings 75 feet apart and 800 feet long; these are connected by three wings 50 feet wide, and are three storeys in height, except for

about 400 feet in the centre, where they are four storeys high. From the centre of this pile rises a large clock tower in the Scottish baronial style, 50 feet square and 200 feet high, forming the most prominent artificial landmark in the Clyde valley. Near the top is placed an enormous clock, the dial of which is 25 feet 8 inches diameter, or 3 feet larger than that of Big Ben at Westminster.

About 6,000 people are employed, of whom about 4,000 come daily from Glasgow by the North British Railway. These are all engaged in the manufacture of sewing machines, of which there are about fifty different classes, subdivided into about 300 varieties, for meeting the special requirements of different trades and manufactures, and weighing from a few pounds to several tons each. The various classes of machines are suitable for sewing any sort of materials, from fabrics as fine and soft as gossamer to heavy sails or large factory belts ten feet wide.

Near the entrance to the works is a brick building containing a well-appointed ambulance; and adjoining it is housed a steam fire-engine by Messrs. Shand, Mason, and Co., which is manned by a drilled company of the workpeople. The water supply is taken from Loch Cochno high up on the Kilpatrick Hills, which provides a strong pressure. Within the works is a large cooking establishment with dining room for the workpeople.

Besides these works and the home establishment at Elizabethport, there are other factories at South Bend in Indiana, Cairo in Illinois Montreal, Hamburg, and Floridsdorf in Austria.

MESSRS. JAMES AND GEORGE THOMSON, SHIPBUILDING YARD AND ENGINEERING WORKS, CLYDEBANK.

The Clydebank Shipbuilding Yard is situated on the north bank of the Clyde, about six miles below Glasgow. The yard is in the form of an irregular quadrilateral, Plate 139, having a total area, including fitting-out basin, of about 50 acres, comprising a shipbuilding and a marine engineering department, with equipment adequate for the

largest class of work in vessels and machinery. The yard is situated close to the terminus of the Clydebank branch of the North British Railway; and a siding is led into the yard, with branches extending to different parts, one branch being led alongside the building berth of H.M.S. "Jupiter" at present under construction, so that the heavy armour-plates may be lifted directly on board the vessel.

The main entrance is at the north-east corner of the yard, from which a broad roadway leads down the centre of the ship-yard. Immediately after entering, on the right-hand side is a block of substantial buildings forming two sides of a square, in which are situated in the basement the counting house, model hall, and the engine-works drawing-office, and on the first floor, a directors' board-room, ship-yard drawing-office, and the tracing department. The second floor is entirely devoted to the photographic department, in which a large amount of work is done. Immediately in front of the offices is a large square space devoted to the storage of plates and angles, and other steel shipbuilding material. The plates are stowed on edge in iron racks, so that they can easily be identified by their marks without handling. The plates are lifted into their positions by means of four steam 5-ton travelling cranes; and when required they are lifted by the same means upon trucks running on the portable narrow-gauge railway, of which there is a complete system throughout the yard.

Passing along the main roadway, on the left-hand side is the frame-bending shed, in which are three angle-iron furnaces, each about 61 feet long, with ample space around them for setting and bevelling frames, and for the scrive boards which are used for giving the required shape to the frames. In this shed is the usual equipment of punches and shears for dealing with the frames, as well as a hydraulic machine for cutting channels and angle-bars, and a machine for straightening and planing angle-bars. Adjacent to the angle-iron furnaces are four Lancashire boilers, 28 feet long and 7½ feet diameter, supplying steam at a pressure of 120 lbs. They are fitted with Proctor's mechanical stokers, the coal being raised by an elevator and distributed by means of a screw worm. The main

engine for driving the ship-yard machinery is a horizontal compound engine by Robey and Co., having cylinders $18\frac{1}{4}$ and 30 inches diameter with 40 inches stroke, and indicating about 300 H.P. The power from the engine is distributed by means of twelve $5\frac{1}{2}$ inch cotton ropes working on a grooved fly-wheel and actuating two main lines of shafting. There is also a complete hydraulic installation for supplying pressure to a large hydraulic plate-flanging machine, to two large man-hole punches, and to hydraulic riveters, cranes, capstans, &c.

The iron-workers' shed is about 350 feet long by 150 feet broad, and is constructed in three bays with two lines of main shafting. In this shed are twenty-seven shearing and punching machines of various sizes, some of them exceptionally powerful and capable of dealing with plates $1\frac{1}{2}$ inch thick, suitable for the protective decks of the largest war vessels. Among other machines is a powerful hydraulic machine by Hugh Smith and Co. for flanging keel-plates, garboard plates, bulkhead plates, &c.; it is capable of flanging plates $1\frac{1}{2}$ inch thick when cold. There is also a large set of plate rolls by Shanks and Co., of Johnstone, capable of dealing with plates 35 feet long and $1\frac{1}{2}$ inch thick. The top roll is a solid steel forging, weighing 45 tons. Adjacent are punches, shears, and planes to deal with large plates. There are also in this shed a number of circular saws, a band saw, and several radial drilling and countersinking machines.

The ship-yard department also comprises a large engineers' shop for dealing with all the work in connection with water-tight doors, pumping, ventilation, steering gears, and other engineers' work independent of the main propelling engines for the vessels. In this engineering department alone about 500 men are employed at the present time.

There is also a large forge and smithy containing about a hundred fires. The joiners' shop is 200 feet long by 150 feet wide. It is on one floor, and contains a number of modern wood-working machines by both British and American makers. This shop also contains a cabinet-making and polishing department. There is a large saw-mill, rigging loft, electrical department, plumbers' shop,

and boat-building shop, moulding loft, and pattern shop. There are a large number of launching berths, four of which are available for the construction of the largest vessels, while the situation of the yard opposite the river Cart allows ample space for launching vessels of the largest size.

The fitting-out basin is 700 feet by 300 feet, and has a depth of 24 feet at low water, so that the largest war vessels may remain afloat during construction. On the east side are sheer legs capable of lifting 120 tons, as well as two light electrical cranes; and on the west side is a 20-ton travelling jib-crane.

The Engine Works are situated on the west side of the yard, and are entered from the main entrance, as well as from a separate gateway further west. The west entrance leads into a large yard, part of which is employed as a light plate and angle-bar store; and the first building passed on the left side is the pattern shop, a long building extending across to the main entrance. It is lighted by skylights running the whole length of the roof, and by a double row of windows in the walls. The larger patterns are made on the ground floor, and the lighter work is carried on in a large gallery which extends completely round the shop. The shop is equipped with lathes, planing, and stripping machines, circular and band saws, and other special tools, and is lighted by electric light. The drawing office is on the basement of the next building in order, and above it are the tracing offices; while further on are entrances to the counting-house, and offices in connection with the engine works.

The boiler shop is situated on the right hand of the yard, and consists of three bays, two of which serve as erecting shops and are each provided with three overhead travelling cranes; the third bay is occupied by various kinds of furnaces and hydraulic flanging tools, smiths' fires, and the machine-tools necessary for the equipment of a modern boiler shop. In the east wall are numerous large doorways, for conveying plates into the shop from the store yard; they are provided with suspended doors, counterbalanced so as to be easily opened and shut. The chief exits are at the south end, where the yard railway enters each of the two erecting bays, and connects them directly with the sheer legs at the fitting-out basin. The

heavier machine-tools are therefore placed at the north end, so as to reduce the transport of materials to a minimum, and to secure their continuous progress towards the point at which they will leave in a finished condition. The wagons conveying the heavy plates enter the shop at the north end; and immediately alongside the rails, which extend across the bays, are placed a couple of plate-edge planing machines, the larger capable of accommodating a plate 38 feet long. Here is also placed a vertical machine for cutting ovals or circles for manholes and their doors. Further on is situated the engine house. A tandem compound engine is employed to drive all the machinery of this department, except those special tools which have independent engines attached to them. A set of compound surface-condensing pumping engines, with cylinders 12 and 20½ inches diameter and 18 inches stroke, is also situated alongside, with steam accumulator, which supplies all the hydraulic tools in this and the other departments of the engine works through a system of hydraulic pipes, distinct from the system laid throughout the shipbuilding department.

Beyond the engine house is the large plate-furnace 20 feet long by 10 feet wide, with its table in front. Over the table swings a radial steam-hammer, having both hand and hydraulic traversing gear for directing the blow of the hammer. The furnace is served by a hydraulic radial crane and a couple of warping drums. In the third or westernmost bay is one of Tweddell's large double-power flanging machines with horizontal bottom cylinder, served by a 6-ton hydraulic crane of 20 feet radius. Another Tweddell machine of smaller size with special furnaces follows alongside; and further south is situated a large tube-staving press, designed and constructed in the establishment. The method of staving and enlarging the ends of tubes and of solid stay-bars by hydraulic pressure has been employed in these works for a number of years, and has been successfully applied to stave and enlarge the ends of the screwed tubes which form the elements of the Belleville boiler. A couple of air furnaces serve this press. Nearly opposite are a couple of multiple boring and drilling machines, with traversing tables 8 feet long and 6½ feet wide; and near these in the centre bay is a powerful set of vertical

cold-plate rolls, which can bend plates 12 feet wide; they are triple geared, and are driven by an independent pair of vertical reversible engines. Alongside is a set of horizontal plate-rolls; and opposite are several punching and shearing machines, between the first and second bays.

Returning to the third bay and continuing southward, there will be found a number of radial drilling and tapping machines, and a set of two large horizontal boring and tapping machines. The latter are capable of traversing a surface 16 feet long by 12 feet high, and have steel spindles $3\frac{1}{4}$ inches diameter; they are employed to tap the front and back tube-plates of tubular boilers, but are at present boring and screwing the holes in the lower side of the steam collectors of the Belleville boilers. In this bay are also situated a number of smiths' fires with special appliances for dealing with angle-bar work. Towards the south end is the screwing department, which is quite distinct from a similar one connected with the engine shops; and as all boiler tubes are received in straight lengths, without being swelled, staved or screwed, a large amount of work has to be done here. The machines employed include a duplex tube-screwing machine for screwing simultaneously both ends of a tube up to $4\frac{1}{4}$ inches diameter, a screwing and turning machine, and several double-geared self-acting open-spindle capstan-rest chasing lathes.

The machinery for drilling and riveting the shells of boilers is to be found towards the south end of the centre bay, and comprises two sets of boiler-shell drilling machines. One set is provided with four working heads, each carried by a radial arm arranged to travel on the bed of the machine, and provided with reversing motion for screwing and tapping. The other machine has three independent heads, movable horizontally and vertically by rack and pinion, whose drilling spindles can work over a boiler 21 feet long and of the largest diameter. At the south wall is placed a powerful hydraulic riveting machine by Messrs. Brown Brothers; the frame of the machine is formed of forged steel slabs, the hydraulic cylinders are of cast steel, and the gap is $8\frac{1}{2}$ feet. On the other side of the bay are two smaller hydraulic riveters, having an independent accumulator, which is supplied by a duplicate set of double-ram

2 x

hydraulic pumps driven off the main shafting. Portable riveters are employed for much of the lighter classes of work, and are moved by hydraulic lifts attached. The buildings are lit by electric light, as well as by a large lucigen apparatus; and the narrow-gauge railway runs throughout the bays.

Leaving the boiler shop by a southern exit, the smithy lies to the west; it is a long building extending between the boiler and machine shops. It accommodates twenty-four smiths' hearths arranged on either side, which together with those in the boiler shop are supplied with air-blast by a large duplex blower, placed at the north end of the building. At this end are also situated the larger steam-hammers with their reverberatory furnaces opposite, and served by hydraulic radial cranes. Four double sets of steam-strikers, a hot saw, and a number of steam-hammers of various sizes ranged up the centre of the shop, make up the larger tools in this department. Continuous with the smithy is the brass foundry, where all the brass work required by the shipbuilding and engineering departments is cast. There are ten crucible furnaces, two air furnaces each capable of melting 6 tons of brass at a time, three drying stoves, loam mill, grinders, band saw, and the various necessary store-rooms. The foundry is served by a 10-ton overhead travelling-crane, besides other hydraulic and hand cranes.

The machine and erecting shops may be entered direct from the south end of the smithy, and consist of four main bays. The first is 35 feet wide, the other three are each 50 feet wide, and provide a height of 40 feet from the floor-level to the underside of the crane girders; they are employed respectively as receiving shed, large machine-shop, erecting shop, and small machine-shop. The engine-shop store is situated at the north of these buildings, and is entered by various doors from each of the larger bays.

The receiving shed has a standard-gauge railway laid along the entire length, with turntable and cross rails at the north end; and is traversed by a 6-ton locomotive jib-crane, which removes materials from the railway wagons brought in by the yard locomotive, and deposits them in positions convenient for the overhead travelling cranes of the machine shops to remove them.

The large machine-tool shop is the next in order. The dressed and ground tools supplied to the machine attendants form a separate department; and the machines specially set apart for preparing them include two universal milling machines, a shaping machine, milling-cutter grinders, Morse-drill grinders, emery grinders, and a number of ordinary grindstones. All the milling cutters, twist-drills, and other small tools used throughout the works, are made and re-ground in this shop, and are distributed ready for use. In this shop will be noticed two vertical milling machines, one having a bed with longitudinal, transverse, and circular motions, while the other has a treble-geared milling spindle, and is capable of working over a surface 10 feet long by 4 feet 7 inches wide and 8 inches deep. Opposite is a powerful treble-geared lathe, designed to deal with the heaviest class of connecting-rods and thrust shafts; it is 20 feet between the centres, and has two saddles with independent screw-motion. Alongside are two other powerful treble-geared lathes, mounted on one bed, so that two pieces of shafting, together 33 feet in length, can be driven by each head; if the centre heads are removed, the bed will admit between the centres a shaft 76½ feet long to be turned. A set of four slotting machines is placed about the centre of the bay; and on the north side of the cross rails are three combined planing and slotting machines. One can deal with an area 21 feet by 17½ feet high; another can slot and plane over a surface 20½ feet long by 14 feet high; and the third can take in pieces 12 feet long and of an equal height. At the north end of the bay is situated a set of four universal boring, drilling, and tapping machines. Two can work over a continuous surface of about 35 feet by 10½ feet; they have steel spindles 5 inches diameter with 42 inches travel, and have bored cylinders up to 48 inches diameter, also drilling, tapping, and studding their flanges at a single setting. The other two machines have spindles 3½ inches diameter, and can traverse a surface 15 feet long by 10 feet high. Opposite are two large treble-geared shafting lathes, whose beds are continuous; in these was machined the large traversing screw for the 130-ton sheer legs made for the dock, which when finished measured over 76 feet in length, the diameter over the threads being 9½ inches.

At the north end of this and of the centre bay or erecting shop are placed the three engines which supply the motive power. They are tandem compound; one, having cylinders 13 and 19½ inches diameter by 30 inches stroke, drives all the machines in the large machine-tool shop; another of equal size drives the tools in the small machine-tool shop, which forms the fourth bay; and the third, which is slightly smaller, drives the whole of the overhead travelling-cranes. Steam is supplied by three single-ended return-tube boilers, of the dry-back kind, situated immediately outside the buildings at the north-west corner. They are 14½ feet mean diameter by 9 feet 3½ inches long, each having three furnaces 3 feet 9 inches diameter, and a working pressure of 120 lbs. per square inch.

The erecting shop is served by two 40-ton overhead travelling-cranes, which run the whole length of the bay upon built wrought-iron girders supported on cast-iron columns; and a number of hydraulic radial cranes and hoists of varying power, up to 5 tons, are placed in advantageous positions. The largest machine-tool in the shop is placed at the north end of the erecting bay. It consists of a boring and planing machine combined. There are two massive standards with a cross-slide, of the same general kind as in an ordinary planing machine, 18 feet apart, and capable of taking articles 13 feet high under the cross-slide. For planing, the work is stationary, and the cross-slide is caused to move, the limit of travel being 12 feet; and two tool-boxes traverse the slide. The columns are joined at the top by a cross-beam; the latter carries the bearing in which the journal of the vertical boring-bar turns, when the machine is being used for boring. The boring bar is driven from a separate counter-shaft. The table will also revolve for turning any circular work, the tool-box being held on the saddle of the cross-slide. In this machine, cylinders of the largest size can be bored, faced on ends, turned on outside, and have the port faces planed at one setting; cylinders up to 113 inches diameter have been so treated. Near this machine are placed two 8-inch spindle vertical boring mills; they are powerful machines, and can take in work 8 feet wide between the standards and 6½ feet high, and their spindles have a travel of 4 feet. In this bay are also four sets of

boring, tapping, and studding machines, which have also a milling arrangement fitted. The drilling spindles are 3 inches diameter, and have a feed of 3 feet, and can operate over a continuous surface 40 feet long by $10\frac{1}{2}$ feet high.

In the last or fourth bay is a varied assortment of all the numerous classes of smaller machine-tools, including various screw-cutting lathes and a complete set of seven lathes ranging from 6 to 12 inches centres. About the centre of this bay are placed a number of drilling and tapping machines; and further southward is a multiple drilling machine, arranged to drill at one time ten holes $1\frac{1}{4}$ inch diameter by 1 inch deep per minute through steel plates $11\frac{1}{2}$ feet wide by 15 feet long, or through drums 4 feet diameter by 10 feet long. The machine is specially designed to drill the drums of water-tube boilers, such as those of the "Normand" kind, which have recently been fitted here into the torpedo-boat destroyers "Rocket," "Shark," and "Surly." The southern end of this bay is exclusively devoted to the manufacture of parts of water-tube boilers; and at the present time various parts are being made in connection with the Belleville boilers which are being fitted on board H.M.S. "Terrible." Amongst the machinery laid down for this purpose is a band-saw for sawing tubes and coupling pieces, which admits $2\frac{1}{2}$ feet deep and 4 feet between the saw and frame, and is also employed for sawing out the jaws of piston and connecting-rods, &c. There is also a three-spindle machine, specially designed to finish the end boxes, into which the tubes of Belleville boilers are screwed; a couple of milling machines; several surfacing lathes; a double-geared screwing and facing machine; as well as an assortment of hand tools and gauges. On an upper floor in the same bay are situated the brass-finishing and iron-finishing shops, which also accommodate a large variety of all classes of iron-working and brass-working machine-tools. A service of hydraulic radial cranes and hoists removes materials from one level to the other; and in connection therewith a system of overhead travellers has been arranged throughout the entire flat.

The number of men employed in all departments of the works when in full operation is upwards of 5,000.

MESSRS. WILLIAM SIMONS AND CO., LONDON WORKS, RENFREW.

These works are situated on the river Clyde about six miles below Glasgow. The firm was established in 1810, and the works at the present time occupy nearly fifteen acres, comprising engine-shops, foundry, boiler shed, smithy, and the various other departments required in a complete engineering and shipbuilding works. The river frontage is about 900 feet. Besides vessels for the mercantile marine, the particular work turned out consists of dredging vessels and ferry steamers of all kinds, of which there are always a number to be seen in the course of construction. Of the latter kind of craft, the elevating-deck ferry-steamer "Finnieston," which now so successfully bridges the Clyde at the busiest part of Glasgow Harbour, may be specially noted as having been designed and constructed here. Amongst the most recent vessels completed is the 1,300-ton stern-well hopper-dredger "Percy Sanderson," constructed for the European Commission of the Danube; it is fitted with a chain of dredging buckets and an independent sand-dredging pump. Three powerful stern-well hopper-dredgers have recently been delivered at Portsmouth Dockyard; and two bow-well hopper-dredgers have been constructed for the Russian Government. One of the latter is fitted with a special disintegrating apparatus for dealing with hard material, so that this can be easily discharged ashore through piping by means of a current of water from a centrifugal pump, or through the dredger's own shoots, or overboard into barges alongside. There is to be seen under construction, and well advanced, a 1,200-ton sand-pump hopper-dredger for the Natal Government, fitted with two 33-inch sand-dredging pumps. Alongside of this is a powerful barge-loading dredger for the Mersey Docks and Harbour Board, which is nearly ready for delivery, having buckets of about 23 cubic feet capacity each. Two other equally powerful barge-loading dredgers are on hand for Portsmouth and Devonport Dockyards. Steel is principally employed in the construction of the dredging machinery and buckets. Ripping claws or picks of special form are provided on several of the bucket dredgers, for cutting up hard material. It is the custom to

launch these vessels in a complete state, having their machinery on board and ready for the steam trials. It will be observed that the vessels now on the stocks possess numerous items of equipment for efficiency and comfort, which compare favourably with first-class passenger steamers: including electric light for night working, steam-steering gear, feed-water heaters, filters, and boiler-circulators. An interesting collection of models of the special work turned out is to be seen in the model room. The number of men employed is about 1,300.

MESSRS. A. F. CRAIG AND CO., CALEDONIA ENGINE WORKS, PAISLEY.

These works occupy over four acres, and are situated on both sides of Macdowall Street, at the north end of the town. They comprise foundry, engine, machine, and smiths' shops, and steel works for the manufacture of steel spiral blades, on the south side of the street; and boiler shop on the north side.

The foundry is well equipped for turning out all kinds of castings up to 25 tons. The principal shop is fitted with a 20-ton power travelling-crane, and the other parts of the building are supplied with steam cranes of various sizes. The cupolas are capable of melting 40 tons a day, for which the material is lifted to the platform on cradles by a steam crane. The various yards are also supplied with steam cranes, for handling castings after leaving the foundry.

The heavy machine and fitting shops occupy the ground floor of the main block of buildings, wherein there is a 15-ton power travelling-crane driven by endless rope, by which the heaviest machines are served. The remainder of the heavy machinery is in the west end of the block. The second and third floors are furnished with lighter machinery for the manufacture of special machines, such as carpet looms, clipping and cropping machines. The latter are made with two, three, or four spirals, to cut all widths of cloth up to 13 feet, and are designed for clipping and cropping all classes of

textile fabrics. The spiral blades for these machines are entirely made on the premises by special machinery, by which they are rolled, file-cut, concaved and twisted, tempered, and ground ready for putting into the machine. The whole of the works on the south side of the street are connected by a narrow-gauge railway, on which runs a locomotive, to facilitate the transport of work from one department to another.

The boiler shop on the north side is fitted for a general class of work, including land and marine steam-boilers, oil boilers, tanks, roofs, &c. The number of men employed is over 400.

MESSRS. FLEMING AND FERGUSON, PHŒNIX SHIP-YARD AND ENGINE WORKS, PAISLEY.

These works are situated on the banks of the river Cart, immediately adjoining the new harbour. They were founded in 1877, and at the present time cover an area of about nine acres.

In the Ship-yard are six berths, so that this number of vessels can be under construction at the same time. As the yard is situated on a bend of the river, vessels up to 400 feet in length can be built and launched, the depth of water in the river at spring tides being 18 feet. The ship-yard is fully equipped with all necessary appliances, consisting of plate and angle furnaces, plate-bending rolls, punching, shearing, and planing machines, steam-hammers, &c.; also complete water service for working hydraulic riveters. The yard is also equipped with spar shed, saw pit, moulding loft, drawing-board sheds, frame-setting shed, smithy, and joiners' shop with circular saws, turning lathes, planing, moulding, mortising, and other wood-working machines. The river frontage is 420 yards, two-thirds of which was piled after the river had been deepened, and a wharf was also constructed at the same time. On the wharf are erected powerful sheerlegs 120 feet in height, capable of lifting and placing on board vessels any weight up to 90 tons, thus enabling

vessels up to 4,000 tons to be engined, rigged, and completed by the builders at their own yard.

The Engine Works consist of smithy, boiler shed, and engine shop. The smithy is fitted with all appliances for carrying on the work of that department. The boiler shed is equipped with the most modern tools; the heavy lifting and transferring are done by a 50-ton travelling-crane and a 40-ton swing-crane over the riveting machine, both being power-driven; and for the expeditious manipulation of lighter material a number of hydraulic cranes have been fitted throughout this department. The riveting of boiler shells is done by a large and powerful hydraulic riveter, having 10½ feet gap, which enables large boilers to be made and riveted with only a single plate in the shell. The riveter is constructed to work at a pressure of 150 tons per square inch, and is adjustable to suit the power required. The hydraulic flanging machines, in addition to ordinary flanging work, stamp furnace-fronts, man-hole doors, and ends for water-tube boilers, each of which operations is performed at one stroke.

In the engine shop are two overhead power-driven travelling-cranes capable of lifting 50 tons each; a large wall planing-machine, constructed to plane 18 feet vertically and having 12 feet horizontal travel; special lathes constructed by Messrs. Lang and Son of Johnstone, Messrs. Smith and Coventry of Manchester, and Messrs. Campbell and Hunter of Leeds. There is also a full supply of drilling, planing, and slotting machines, besides numerous other tools for special work. The tools in this shop are of the most modern and powerful description, including those necessary for turning out engines up to 10,000 horse-power.

Power for engine shop, boiler shed, and smithy, is supplied by one of the firm's "Clyde" water-tube boilers, constructed for a working pressure of 200 lbs., which gives steam to one of their quadruple engines driving the works. Commodious new offices have recently been erected, including a model room, in which are shown about a hundred interesting models of steamers, steam yachts, hopper dredgers, barge-loading dredgers, hopper barges, &c. The number of men employed is about 600.

MESSRS. FULLERTON, HODGART, AND BARCLAY, VULCAN WORKS, PAISLEY.

These works are situated in Renfrew Road, Paisley, close to the Abercorn station of the Glasgow and South Western Railway. Founded in 1838 by Messrs. Craig and Donald, the firm later became Craig and Fullerton, and finally assumed its present designation. The work produced comprises triple-expansion, compound, and single-cylinder engines, condensing and high-pressure, of all descriptions and for all powers. For upwards of thirty years a speciality has been made of hydraulic machinery; and a large set of hydraulic engines, accumulator, and portable cranes has just been completed for the Clyde Trust at Cessnock Dock, Govan. The foundry, which is kept as a separate department, is capable of turning out the largest castings, and has a considerable trade in supplying the foremost marine engineers on the Clyde. Both works are well equipped with hydraulic power, and the cranes are so placed as to make the whole floor space available. The number of persons employed is about 500.

MESSRS. JOHN LANG AND SONS, LATHE AND TOOL WORKS, JOHNSTONE.

These works were erected in 1874, and since then have been steadily growing, so that additional ground has had to be acquired, on which are being erected show rooms for stocking larger tools than can be accommodated in the present buildings. Lathes of all kinds from 6 to 20 inches centres constitute the special work here produced, and large numbers of these and of machine-tools are always in stock and in progress. The machine shop is well equipped with tools of the latest invention. These works were the first in the country to adopt machine-cut teeth in all gear wheels used in the manufacture of lathes and machine-tools; and the plan has been further extended to cutting the teeth in all racks by

machinery. A notable feature in the lathes is what is known as Lang's handle feed-motion, which enables the workman to change the rate of sliding or surfacing feed by the simple movement of a handle within easy reach. It is applied to all lathes which are self-acting by shaft, and to all screw-cutting lathes which have self-acting motion independent of the screw. Specially sensitive levels and measuring machines are used for adjusting the tools in the works, and spindles can be turned truly round with accuracy to one ten-thousandth of an inch. The gear-cutting department has about twenty machines in constant operation, cutting teeth in spur, bevel, worm, and spiral gears, and in racks. These machines have been manufactured in the works, and most of them are entirely automatic in their action. The latest addition to this department is a machine for cutting the teeth in bevel wheels theoretically correct. The number of men employed is about 200.

MESSRS. JOHN M'DOWALL AND SONS, WALKINSHAW FOUNDRY, JOHNSTONE.

This business was established in 1823 in another part of the town, and removed to the present premises in Walkinshaw Street in 1846. The works occupy about two acres, and employ over 150 men. The main buildings extend about 300 feet by 200 feet, some of them being two and three storeys high. For some years a portion of the premises was occupied as a foundry; but owing to the pressure of work for the government dockyards about the time of the Crimean war, and to the general development of saw-mill and wood-working machinery, the foundry was converted into an erecting shop, and the castings were procured from other foundries in the town.

In the pattern shop, which is 100 feet long by 40 feet wide, are a number of machines for facilitating the output of work and for show; and in connection with this department are four pattern-stores. The smithy, 150 feet long by 36 feet wide, has six hearths, steam-hammer, and cranes; one end of this building is arranged for stock castings for the lighter portions of the machines. On the ground floor

of the turning and planing shop are the usual turning lathes, planing machines, horizontal boring and milling machines, the latter being arranged with large tables for carrying the whole frame-work of machines under construction, thus allowing the various operations to be carried out as far as possible at one setting. Round this shop runs a gallery for turning and planing lighter work; and a continuation of it is occupied as an erecting shop for light machinery. There are two erecting shops, one fitted with power travelling-crane, and the other with two stationary cranes, while two suitable derrick cranes are provided for the yards.

The work turned out consists of every kind of wood-working machinery for the conversion of the tree or log into various scantlings, and comprises vertical saw-frames for logs and trees up to 5 feet round or square, circular-saw rack-benches for saws up to 78 inches diameter, horizontal and vertical band-sawing machines, and horizontal reciprocating saw-frames for logs; in addition to these there is an endless variety of machines for sawing, planing, moulding, mortising, tenoning, boring, turning, nailing, dove-tailing, &c., for saw mills, shipbuilding yards, railway carriage and wagon factories, joiners, carpenters, engineers, pattern makers, cabinet makers, packing-case makers, wheelwrights, match manufacturers, &c.; the pattern stores contain many hundred varieties.

High-class steam engines of the high-pressure, condensing and compound type, with the necessary shafting, gearing, &c., have all along formed a portion of the manufactures, more especially in connection with driving saw-mill and other wood-working machinery. These have given the most economical results; coal has been dispensed with entirely in many cases where the compound engines have been adopted, the steam being generated by the refuse from the planing machines. To keep down the cost of production, and ensure quick delivery, a large number of machines are made to stock, thus giving an opportunity of inspecting them beforehand.

MESSRS. DAVID J. DUNLOP AND CO., INCH WORKS, PORT GLASGOW.

These works were established in 1871, and are well adapted for the requirements of shipbuilding and engineering. They occupy a large space on each side of the Greenock and Port Glasgow road; the shipbuilding yard and engineering shops lie between the road and the river, and the boiler works and smiths' shops between the road and the Caledonian Railway. The works are in direct communication with the railway, and are in the immediate neighbourhood of three graving docks. Special accommodation is provided for repairing ships, engines, and boilers. Amongst other appliances is a 70-ton derrick-crane, which has the advantage over sheer-legs of enabling a length of about 100 feet of the engine and boiler space in a ship to be under the command of the crane without unmooring the ship, thereby enabling a steamer to receive all her machinery without being shifted.

The special work produced here includes the combined steam and pneumatic governors for marine engines, which have been applied to several ships of the royal navy, to the Cunard steamers "Campania" and "Lucania" of 30,000 horse-power, to the twin-screw steam-yacht for the Emperor of Russia, to vessels of all sizes in foreign navies, and to the leading steamships afloat. The governor was described at the last Meeting of this Institution in Glasgow (Proceedings 1879, page 406). The number of men employed is from 1,500 to 1,700.

MESSRS. RUSSELL AND CO., KINGSTON SHIPBUILDING YARD, PORT GLASGOW.

This yard, of which Mr. W. T. Lithgow is now the sole proprietor, is situated about a mile from Port Glasgow station, and is close to the Bogston station of the Caledonian Railway from Glasgow to Greenock. It has been recently enlarged, and now covers about

nineteen acres. There are at present nine berths, occupied by six sailing ships and three steamers in various stages of construction; the recent addition will give room for six more berths. The Kingston Saw Mill, long occupied by Messrs. Thomas Lamb and Sons, forms part of the same premises, and is worked in connection with the shipbuilding business. The yard is well arranged for economical work, and the model room contains a great number of models of the most recent types of sailing ships. The number of men employed is about 1,350.

MESSRS. SCOTT AND CO., SHIP-YARD AND ENGINE WORKS, GREENOCK.

These shipbuilding works were started in the year 1710, by the great great grandfather of the present senior partner Mr. John Scott, C.B., and have been carried on from that date by the descendants of the founder. The combined area of the works is about thirty acres; as the business has gradually expanded, the establishments are not all adjoining, but are divided into four, comprising three shipbuilding yards and the engine works.

The Cartsdyke or east yard is the oldest of the three, though not the site of the original works, which were in another part of the town. This yard contains the drawing offices and counting house, and from here all the ship-yard details are carried on. Here are six building berths, with all the necessary frame-turning, smith, joiner, carpenter, and other sheds, including a complete hydraulic plant for dealing with the heaviest class of work. The yard is served by a private siding from the Caledonian Railway. On the other side of the street are the saw mills and wood stores.

Further west towards the town is the middle yard, in which are four building berths. This yard is also fitted with all the requisite machinery for dealing with work rapidly and cheaply. Here also is a slip, on which can be hauled up vessels of 300 tons for overhaul and repair.

Again a little way on is the Dockyard, containing a dry dock 360 feet long, with pumping plant capable of drying the dock in $1\frac{1}{2}$ hours. This yard contains a large joiners' shop, saw mill, engineers' shop, smith shop, and a repairing basin. It is contiguous to the Victoria Harbour of the Greenock Harbour Trust, where is placed the 100-ton crane, for fitting out vessels with their engines and boilers.

A short distance from this yard are the Engine Works, containing pattern shop, iron and brass foundries, turning shop, smith shop, iron and brass finishing shops, engine erecting, boiler, and copper-pipe shops. These are fitted with a most complete assortment of labour-saving machinery, for dealing with the heaviest class of marine engines and boilers, including an overhead travelling crane in the boiler shed of 100 tons lifting power. Recently there were lifted by this crane four boilers, which weighed, without mountings, 89 tons each.

The capacity of the ship-yards is about 30,000 tons per annum, and of the engine works about 35,000 I.H.P. There have been employed in all the different departments about 4,500 men and boys at one time; but this number varies considerably with the amount of work being done.

MEMOIRS.

William Henry Armstrong was born at Huntingdon on 1st September 1865. He served his time for four years from 1882 to 1886 in the works of Messrs. James Watt and Co., Soho, near Birmingham, and was afterwards retained there as a draughtsman for about a year, and then as an erector. In 1887 he was sent to Salford, to assist in overhauling the sewage pumping engines there. In November 1887 he went to Calcutta to superintend the erection of beam pumping engines, and also the general work at the new pumping station at Halliday Street, then in course of construction. Having completed this work he supervised alterations to the engines and boilers at the Wellington Square pumping station. On 1st November 1889 he was appointed superintendent of the latter branch of the Calcutta Water Works, in which capacity his duties also included the practical examination of authorized plumbers for the municipality. His death occurred at Calcutta on 23rd May 1895, in his thirtieth year. He became an Associate Member of this Institution in 1894.

William Bailey was born at Queensbury, near Halifax, Yorkshire, on 25th March 1853, his father being for many years chief engineer at Messrs. John Crossley and Sons, Dean Clough Mills, Halifax. After being educated at Heath Grammar School, Halifax, and at Pannal near Harrogate, he served his apprenticeship with Messrs. Fielding and Platt, Gloucester. On its completion he went for a short time to Mr. Brain in the Forest of Dean, and then to London, where he entered the office of Mr. Ralph H. Tweddell. There he ultimately became manager, and remained so up to the time of his death, which took place suddenly on 3rd August 1895, at the age of forty-two. He became a Member of this Institution in 1886.

Herbert Fletcher was born at Bolton on 25th April 1842. After being educated at the Windermere Grammar School, he went to Messrs. Hick, Hargreaves and Co., Soho Iron Works, Bolton, to study mechanical engineering; and also learnt surveying under Mr. Elias Dorning, of Manchester. From 1862 to 1868 he managed for his father the Clifton and Kearsley Collieries, near Manchester; and from 1868 the Ladyshore Colliery, near Bolton. He succeeded his grandfather and uncle in the post of mineral adviser to the Duke of Buccleuch at Burnley, and was consulting engineer at the Atherton Collieries, near Bolton, until 1874. Besides designing many practical improvements in small appliances for coal pits, he adopted the method now used at Ladyshore Colliery of filling up the goaf, as the coal was extracted, with material from all parts of the mine, instead of sending the latter to bank, and brought down for that purpose cinders and other refuse available: the object being to take the weight as it comes on, better than by props or chocks, and to leave no space for the accumulation of gas. For the last fifteen years he worked hard to abate the nuisance of smoke arising from boiler fires. He adopted a mechanical furnace of the coking kind, and for many years his chimneys have been practically smokeless; and steam has been raised with the maximum of economy from refuse coal from the colliery, for which no reasonable price could be obtained. In these furnaces he made many improvements. For some years past he had devoted much attention to the general question of smoke abatement, and spent much time in collecting information for a report to the Smoke Abatement Society, with the object of showing conclusively the merits of the different methods of boiler firing, and proving that the mechanical furnace was the most economical in utilization of both fuel and boiler space, and that the kind of furnace which made the least smoke was financially the most economical. He was a member of the Bolton Town Council and of the Lancashire County Council. His death occurred near Bolton from failure of the heart, on 16th September 1895, at the age of fifty-three. He became a Member of this Institution in 1872.

Charles Williams Guy was born at Hull on 31st July 1836. He served his time from 1851 to 1856 in the engine works of Messrs. E. B. Wilson and Co., Railway Foundry, Leeds. With the object of learning marine-engine construction he went in 1857 to Messrs. Robert Stephenson and Co., Newcastle-on-Tyne. In 1859 he went as assistant to the locomotive superintendent on the Recife and São Francisco Railway, Pernambuco; and from 1861 to 1863 was engineering agent and technical adviser in Java for Messrs. G. Buchanan and Co., London. In 1864–5 he was engaged in refitting sugar works on the Wonosepi, Kalang, Sarie, and Becassie estates in Java; and was engineer and works manager in 1866–9 on the Tjipiring and Adhiwerna sugar estates. He was appointed manager in 1870 of the Adhiwerna, Kemantian, and Padokan sugar estates in Java, and remained in that position till 1877. In 1879 he became engineering agent and technical adviser in Java for Mr. William Walker, which position he held till 1885. Subsequently he engaged in business on his own account, and designed certain improvements in sugar-cane crushing-mills. His death took place at Malang, Java, on 9th November 1893, at the age of fifty-seven. He became a Member of this Institution in 1886.

Sir Edward James Harland, Bart., M.P., was born in May 1831 at Scarborough, where his father occupied a position of importance as a medical practitioner. In 1846 at the age of fifteen he was apprenticed to Messrs. Robert Stephenson and Co., Newcastle-on-Tyne; for four years he was in the shops, and in the drawing office during the last year of his apprenticeship, at the termination of which he was taken on as a draughtsman at wages of 20*s.* a week; and when work began to be scarce he went in 1851 to London for two months, which he spent principally in the machinery annexe of the Great Exhibition. Thence he went back to his home in Scarborough; and shortly afterwards to Messrs. J. and G. Thomson of Clydebank, Glasgow, at that time makers of engines only. There he was taken on at his former wages; and shortly afterwards, when they commenced building vessels, he was promoted to assistant draughtsman, and in 1852 to the position of head draughtsman.

In the latter part of 1853 he became manager of the ship-yard of Mr. Thomas Toward on the Tyne, where the whole management devolved upon himself. At the end of 1854 he became manager of Messrs. Robert Hickson and Co.'s ship-yard, Queen's Island, Belfast, where at the outset he was confronted with great labour troubles; but these were successfully surmounted, and fresh orders for ships were obtained. He then purchased the business, and thus commenced his long and prosperous career as a shipbuilder on his own account. In 1862 he took into partnership his assistant, Mr. G. W. Wolff, forming the firm of Harland and Wolff. Their first contract was for three screw steamers, each 270 feet long, for Messrs. J. Bibby, Sons, and Co., of Liverpool. On a repetition of the order, he suggested a greater proportionate length, obtaining longitudinal strength by making the upper decks entirely of iron, thereby forming a box girder of immensely increased strength. The new vessels had four pole-masts and no yards, the aim being to reduce the complement of men by using all fore-and-aft sails. These ships made many successful voyages to the Mediterranean and the owners were so satisfied that they sent an order for three more ships, which were to be again 20 feet longer than the last, but no wider. Yet another feature was introduced into their next ship, the "Persian," built for trade with Venice, which was a port difficult to approach. The new ship was 90 feet longer than any vessel previously entering that port; and in order to give the necessary quickness on the helm the forefoot was cut away, so as to reduce the resistance to turning, and to throw the point on which the ship pivoted nearer to the centre of her length. The overhanging bow with its bowsprit and jibboom was done away with, and the vertical stem without bowsprit was substituted. The iron decks and iron bulwarks with iron rails were found of advantage, for the deck would remain tight without caulking. In order to obviate the difficulty that accompanied any attempt to combine wood and iron in the structure, owing to the different manner in which the two materials are affected by heat and moisture, he filled the spaces between the frames with Portland cement, and covered the plating with cement or cement and tiles. The Cunard line,

which was so soon to find a serious rival in the vessels built at the Queen's Island yard, sent several of their ships to be lengthened, four of which had 63 feet inserted amidships. The long-ship principle was now fairly launched, owners and builders were falling in with the modern notion, and the Belfast yard was full of long ships being built or of short ships being made longer. Messrs. Bibby and Co. ordered three more ships for the Mediterranean trade, and then other vessels followed which brought the number up to twenty, and in none of these was there any sign of weakness. On the formation of the Oceanic Steam Navigation Co. in 1869 an order for six vessels was placed with the Belfast firm; they were to be capable of carrying heavy cargo and a full complement of cabin and steerage passengers between Liverpool and New York, whilst the speed was to be equal, if not superior, to that of the powerful Cunard ships and their rivals of the Inman line. The first ship built for this line was the "Oceanic," launched in August 1870; she was 400 feet long on the keel, 41 feet wide, and 31 feet deep, gross tonnage 3,807, and horse-power 2,000 indicated, and was fitted with two compound vertical surface-condensing engines with tandem cylinders. The first-class accommodation was placed in the centre part of the vessel; the chief saloon extended from side to side, being lighted by ports through either side of the ship. In 1874 Mr. W. J. Pirrie, who had served his apprenticeship with the firm and had also for seven years acted as Sir Edward Harland's assistant, became a partner; and in that year and the next were added to the White Star fleet the "Britannic" and "Germanic," in which the length was increased to 455 feet and the width to 45 feet. Eight more vessels were launched from the Belfast yard for the same line, some of which were large cargo steamers with large space for emigrants. The crowning work of ships built for this line at Belfast was accomplished in the "Majestic" and "Teutonic," which at the time of their construction were the largest vessels in the world, each being 582 feet long by $57\frac{2}{3}$ feet beam and $39\frac{1}{3}$ feet deep, with gross tonnage 10,000. They are twin-screw vessels, with triple-compound engines, and horse-power 18,000 indicated. Since then Messrs. Harland and Wolff have built several cargo and live-

stock steamers for the same line, and a large number for other owners. Such was Sir Edward's aversion to anything approaching slovenliness in work, that Messrs. Bibby and Co. trusted him entirely; and with the White Star line there was never a specification or a fixed price for a ship. Previously the Queen's Island establishment had not included engine works; but in 1880 a large additional piece of land was acquired, and engine shops were erected, since which time marine engines have been constructed there. In 1870 he became a commissioner of the Belfast Harbour Board, but shortly after resigned owing to pressure of business; later on he rejoined, and ultimately became chairman of the Trust; in 1887 he retired from the Board. While Mayor of Belfast he entertained the Prince and Princess of Wales on their visit to the city in 1885, and shortly afterwards was created a baronet. In 1889 he was elected a Member of Parliament for Belfast, and was again returned in 1892 and 1895. In 1887 he was appointed High Sheriff for County Down, and was a justice of the peace. For some time past he had ceased to take an active part in the management of the firm. His death took place suddenly at his residence, Glenfarne Hall, near Enniskillen, from heart disease, on 23rd December 1895, in his sixty-fifth year. He became a Member of this Institution in 1888.

Charles Mitchell was born at Aberdeen on 22nd May 1820. After receiving his early education at a school in the Questrow, and at the Grammar School, he entered as a premium apprentice the engineering works of Messrs. W. Simpson and Co., predecessors of the firm of Messrs. Hall, Russell, and Co. He matriculated as a student at the Marischal College, and in 1840 was first prizeman in the chemistry class. In 1836 considerable additions were made to Messrs. Simpson's workshops, and he assisted Mr. John Coutts, an architectural draughtsman, in preparing the drawings, &c. Some time previous to the completion of his apprenticeship in 1841 he gave drawing lessons in the evening to the late Mr. Andrew Leslie, who at that time was foreman boilermaker with Messrs. Bowman and Vernon, shipbuilders and engineers, and who afterwards became

a shipbuilder at Hebburn on the Tyne. On the completion of his apprenticeship he entered as draughtsman the employment of Mr. Coutts, who had left Aberdeen and had taken in 1840 a building yard on the Tyne, previously used by Mr. William Reay for building wooden vessels, and now forming part of Messrs. Wigham Richardson and Co.'s establishment. Here he commenced on 24th September 1842, the day after the launching of the paddle steamer "Prince Albert," which was the first iron steamer built on the Tyne. Two years later he obtained an engagement with Messrs. Maudslay, Sons, and Field, with whom he remained until 1852, when he commenced a ship-yard at Walker-on-Tyne upon a piece of ground which was then in process of being reclaimed from the river; and the yard was afterwards largely extended by the acquisition of other property. His first vessel, the "Havilah," was launched in 1853, and is still afloat in Australia. In 1862, when the Russian government determined to commence the construction of armour-clads in their own country, they entrusted his firm with the conversion of their wooden dockyards into iron shipbuilding establishments. He accordingly visited St. Petersburg, where he received an order for an ironclad, soon followed by others; and his brother-in-law, Mr. H. F. Swan, resided there for some years as the representative of the firm. In recognition of his services the decoration of the Order of St. Stanislaus was conferred on him. In 1865 for the sake of health he withdrew from the active part he had hitherto taken in the business, and went to reside near London for a time. Subsequently determining to return to Newcastle, he purchased in 1869 the Jesmond Towers estate. His firm having been engaged for many years in building war vessels in conjunction with that of Sir W. G. Armstrong and Co., an amalgamation took place in 1882, the name of the new firm being Sir W. G. Armstrong, Mitchell and Co. The University of Aberdeen benefitted largely by his generosity. In addition to aiding in the extension of the buildings, he gave a grand organ, and provided means to heighten the tower of the Marischal College, which now forms one of the principal architectural features of Aberdeen. In recognition of his munificent bequests, amounting to about £30,000, the Senate of the University conferred

on him in February 1893 the honorary degree of Doctor of Laws. His death occurred at his residence, Jesmond Towers, after a few days' illness, on 22nd August 1895, at the age of seventy-five. He became a Member of this Institution in 1856.

James Murdoch Napier was born on 26th July 1823; and was a son of Mr. David Napier, well known as an inventor and constructor of printing machines. In 1837 he entered his father's works in Lambeth, where he became a skilled workman and draughtsman, and soon displayed considerable capacity for original design. In 1841 he assisted in the construction of the first steam-power gun-finishing machinery used at Woolwich, and in 1844 of a hydraulic traversing-frame designed by Mr. Brunel for the Bristol terminus of the Great Western Railway. He also erected a hydraulic travelling-crane in the locomotive works at Swindon, and assisted in erecting a hydraulic lift for trucks at Bristol. In 1847 he was taken into partnership by his father, the firm thenceforth being known as David Napier and Son. In 1848 he assisted in the design and construction of registering weighing-machines and tipping-trucks for use at Portland breakwater. In 1855 he supplied an elaborate machine for weighing stone at the Tyne works, which not only indicated the weight of the load on the weighbridge, but also registered the gross weight passing over in a given time. In 1851 his firm designed and constructed five automatic coin-weighing machines for the Royal Mint. He also designed an automatic balance, which divided the coins into three classes, "too light," "too heavy," and "medium," the last alone being put into circulation. In 1853 he designed machinery for the Spanish mint; and in 1861 spent some months in St. Petersburg, making plans for the re-arrangement of the Russian mint. In 1862 he designed and constructed the "Chancellor" balance for the Royal Mint. In 1870 he was appointed by the Treasury to visit and report upon European mints, with a view to advise what new machinery would be required, if the mint were removed from its present site. His colleagues on the commission were the deputy master, Sir Charles Fremantle, K.C.B., and Professor Roberts-Austen, C.B., chemist to

the mint. In 1877 he designed and constructed the "Lord Chief Justice" bullion balance for the Bank of England, and a mercurial gauge used with it for indicating speed up to 400 revolutions a minute. He also devised for the Indian mints a machine which ascertains the quantity to be cut off from each blank in order to reduce it to the standard weight, and then removes the necessary amount of metal. In 1853 he devised improvements in letterpress printing machines; and in the following year he designed and constructed a machine for printing the Bank of England notes. Amongst his other numerous inventions were registering tide-gauges, mariners' compasses, barometers, machinery for producing cold the lead bullets for government rifles instead of cast bullets, an apparatus for paying out submarine telegraph cables, machinery for the manufacture of soda, speed indicators, and governors, etc. His death took place at his residence adjoining the works in Lambeth on 23rd March 1895, in his seventy-second year, from an affection of the throat. He became a Member of this Institution in 1870.

Charles Louis Marie Pinel was born in Rouen on 29th May 1843. After being educated in France from 1853 to 1860, he spent two years in England to complete his studies. Some years later he succeeded his brother-in-law, M. Lethuillier, who had founded in 1847 the firm afterwards known as Lethuillier and Pinel, and who was the inventor of the magnetic water-gauge described to this Institution (Proceedings 1860 page 83). On the death of M. Lethuillier in 1863, he undertook the management of the works, which then employed only about thirty hands; and in five years' time he became a partner in the business, which continued to increase. He introduced improved machinery, and invented many appliances connected with boilers, such as a feed regulator, a safety-valve, and a steam stop-valve, all of which were successful. Including the brass and iron foundry, the works now employ more than 300 persons, for whose welfare he established a benefit society sharing in the profits of the firm. He was judge of the Rouen tribunal of commerce for five years; director of the National Bank of France; vice-president of the Rouen Exhibition in 1884; member

of the jury of the Havre Maritime Exhibition in 1887, and of the departmental committee for the Paris Exhibition in 1889. His death took place in Rouen on 5th December 1895, in his fifty-third year. He became a Member of this Institution in 1876.

Professor James Scorgie was born at Aberdeen on 16th March 1835. After receiving an elementary education in one of the parish schools in that city, he was apprenticed in 1850 to a firm of brass-founders there. During his term of seven years he improved his education by private study and by attending evening classes, which were then being started in Aberdeen in connection with the Science and Art Department. In 1855 he gained the first prize for chemistry at the government examination of the Aberdeen School of Science; it consisted of a medal, and a student's prize given by the Board of Trade, the latter entitling him to attend certain classes at the Marischal College. On leaving college he went early in 1858 to London, and later in the year to Bombay, where he obtained a situation in the locomotive department of the Great Indian Peninsula Railway, and remained there for sixteen months. Thence he went to the locomotive department of the Bombay, Baroda, and Central India Railway, at Amrolee, near Surat, and remained there until November 1861, when he was appointed engineer's assistant on the railway bridge at Bassein, which at the time of its erection was the largest bridge in the world, being 4,312 feet long in sixty-six spans of 60 feet. In 1862 he was appointed teacher in the Free General Assembly's Missionary Institution at Bombay; and in 1865 became acting principal of the Sir Jamsetjee Jeejeebhoy Institution at Bombay. In 1866 he was appointed head master of the Akola High School at Berar, and remained there six years. At the request of the Maharajah he was transferred by the government in 1872 to the Jeypore Durbar, where he re-organized the school of Industrial Arts. In 1875 he was appointed professor of mechanism and applied science in the Civil Engineering College at Poona, where he remained fifteen years. In 1868 he was elected a Fellow of Bombay University, for which he was an examiner. He retired from the Indian educational service in November 1890, and returned to

Aberdeen, where in 1894 he was elected a member of the school board. His death took place there after a short illness on 15th July 1895, at the age of sixty. He became a Member of this Institution in 1885.

PATRICK STIRLING was born at Kilmarnock on 29th June 1820, being the son of Rev. Robert Stirling, D.D., so well known for his invention of the regenerative air-engine. From 1837 to 1843 he served his apprenticeship under his uncle at the Dundee Foundry, now owned by Messrs. Urquhart, Lindsay, and Co. On the completion of his term he worked as a journeyman for a short time, and then was employed by Mr. Robert Napier for three years at the Vulcan and Lancefield Foundries, Glasgow, which at that time were occupied with the construction of the machinery for the early Cunard steamers. In 1846 he went to Messrs. Neilson and Co.'s Hyde Park Locomotive Works, Glasgow, and was soon promoted to be a foreman. In 1851 he was appointed superintendent of the short line from Bowling on the River Clyde to Balloch on Loch Lomond, which now forms part of the Dumbartonshire line of the North British Railway. He was next for a short period with Messrs. Hawthorn of Newcastle-on-Tyne, but returned to Scotland in 1853 as locomotive superintendent of the Glasgow and South Western Railway. After remaining thirteen years on this line, he joined the Great Northern Railway in the same capacity, on the retirement of Mr. Archibald Sturrock in December 1866. At that time the Great Northern Railway had not long been formed by the amalgamation of several local lines. In 1876 the number of passengers carried was just over eighteen millions, now it is thirty-three millions; and the train-mileage is now over twenty millions. The extensive works at Doncaster, covering 30 acres, have been constantly employed in replacing, overhauling, or improving the thousand engines engaged on the line. The carriages are also constructed at these works, and he had a large share in their improvement, especially in recent years. The kind of locomotive he constructed was that having large single driving-wheels, with outside cylinders and a bogie at the leading end. This kind had been well developed by John V. Gooch, Robert

Sinclair, John Ramsbottom, and Patrick Connor; but his "big singles," introduced in 1870, formed a much more powerful class than any which had preceded them. He adhered to outside cylinders long after they had been abandoned by most locomotive engineers for the express service in this country, although from time to time he built engines with inside cylinders. His large driving-wheels gave ample adhesion for the work to be done, being heavily loaded with 17 tons on the pair; but with steel rails and a good permanent way this load has not proved at all excessive, and steam sanding apparatus removes any difficulty at starting. The straight-topped boiler without steam dome was another characteristic of his locomotives; and also the method of staying the fire-box crown by coupling it direct to the top of the boiler. He was an opponent of compounding in locomotives, and was adverse to any radical change that would interfere with arrangements which proved successful. His death took place at Doncaster from pneumonia on 11th November 1895, in his seventy-sixth year. He became a Member of this Institution in 1867; and was also a Member of the Institution of Civil Engineers, and an original Member of the Institution of Engineers and Shipbuilders in Scotland.

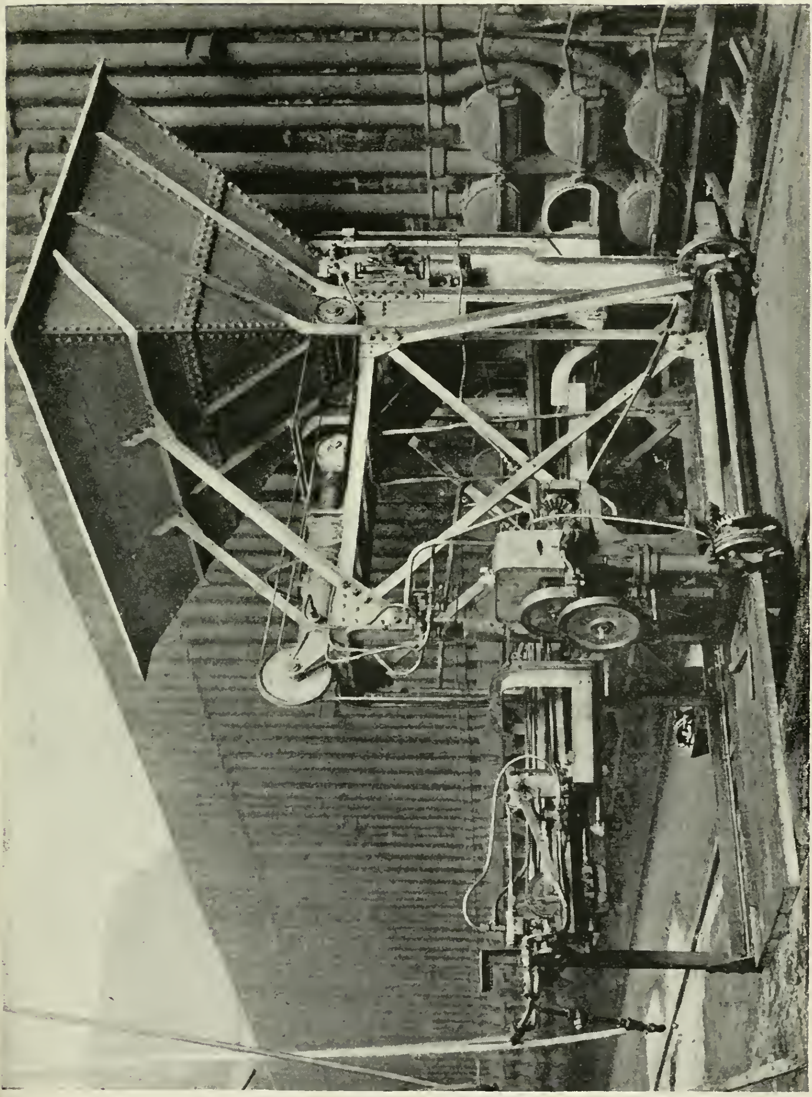
Joshua Alfred Alexander Turner was born at Poona, India, on 10th August 1848. From 1861–66 he worked in the Royal Gun-Carriage Factory and in the Mint at Bombay; and assisted in the erection of engines, boilers, and machinery, for the new Mint there. He was next in the service of Messrs. W. Nicol and Co., Bombay, assisting in the erection of engines, boilers, cotton-presses, &c. He was then appointed assistant engineer in the government mills and steam bakery at Poona; and afterwards became head engineer, and ultimately superintendent and engineer of these mills, and inspector of commissariat mills and bakeries. On the abolition of this appointment in April 1893, and the adoption of the contract system, he retired on a pension. In April 1895 he was appointed inspector of boilers and prime movers under the Madras government; but did not long hold this position, as his death occurred at Poona on 6th September 1895, at the age of forty-seven. He became a Member of this Institution in 1887.

RALPH HART TWEDDELL was born on 25th May 1843 at South Shields, where his father was a shipowner. With a view to entering the army, he was educated at Cheltenham College, devoting his time at first especially to classical studies, and subsequently to preparing himself for the Royal Military Academy at Woolwich. His strong mechanical instincts however led to his being articled on leaving school to Messrs. R. and W. Hawthorn, of Newcastle-on-Tyne. In 1863, while serving his apprenticeship, he invented a hydraulic tube-fixer, which did good work. Two years later he designed a stationary hydraulic riveter, and thus commenced the development of the system of hydraulic tools with which his name is so intimately associated. On the completion of his apprenticeship at the age of twenty-two, he went to sea as an engineer. At that time steam pressures at sea were increasing, and the difficulties of doing good work with the greater thicknesses of boiler plates required were beginning to be felt. It occurred to him therefore to apply hydraulic pressure for riveting; and his first machine, made by and for Messrs. Thompson, Boyd, and Co., of Newcastle, did the work perfectly with a pressure of 1,500 lbs. per square inch, and at about one-seventh of the cost of hand work. One of its special features was the use of a small accumulator, of which the ram fell a considerable distance at each stroke of the riveter, with the result that the suddenly arrested fall of the accumulator weight caused a materially intensified pressure to be exerted at the end of the stroke. By this and other inventions he helped to render possible the increase of steam pressures from 40 lbs. to 200 lbs. per square inch, which, with multiple expansion in engines, has reduced coal consumption from $3\frac{1}{2}$ lbs. to a little over 1 lb. per horse-power per hour. In 1871 he brought out a portable riveter, which constituted an important innovation, giving hydraulic machine-tools a character of their own; and it was with this first portable tool that his uninterrupted connection with Messrs. Fielding and Platt of Gloucester was commenced. The machine proved highly efficient, and its manufacture was then regularly entered upon, various modifications and improvements being from time to time introduced. In 1872 he opened an office in Westminster, and contributed to this

Institution a paper on the application of water-pressure to shop tools and mechanical engineering work (Proceedings, page 188). In 1873 the portable hydraulic riveter was first used for bridge work by Mr. W. H. Panton, on the bridge which carries Primrose Street over the Great Eastern Railway at Bishopsgate Street station, London. The work was done quickly and silently, and the reputation of the machine for this work was thereby assured. By this plan many large bridges in India have been built by native labour with a minimum of supervision. In 1876 the French government, having decided to prepare works at Toulon for the construction of the largest iron and steel warships, determined to adopt a complete installation of hydraulic machine-tools, on the recommendation of M. Marc Berrier-Fontaine, by whom a description of the whole was given at the Paris Meeting of this Institution in 1878 (Proceedings, page 346). In the application of this system to shipbuilding a great amount of time, labour, and cost was saved. For locomotive work the hydraulic riveter was first used by Mr. F. W. Webb at the Crewe Works of the London and North Western Railway; the Italian government used it for riveting gun-carriages, to prevent working due to the shock of firing; and the Gloucester Wagon Co., Messrs. P. and W. MacLellan of Glasgow, and the Great Western Railway, first used it for underframes of wagons. In 1874 Mr. Tweddell contributed a second paper to this Institution on the application of water pressure to driving machinery and working shop-tools (Proceedings, page 166); and in 1878 a third paper on the application of pressure-intensifying apparatus to hydraulic presses (Proceedings, page 45). He was a member of the Research Committee on Riveted Joints, and drew up a table showing rules of practice for riveted joints (Proceedings 1881, pages 293–299). The numerous awards bestowed on him in recognition of his inventions included that from the Centennial Exhibition in Philadelphia in 1876, and the Grand Prix in the machine-tool class from the Paris Exhibition in 1878. His death took place suddenly at his residence, Meopham Court, near Gravesend, on 3rd September 1895, at the age of fifty-two, from aneurism resulting from a fall from his horse a few years ago. He became a Member of this Institution in 1867, and was a Member of

Council from 1883 to 1885; he was also a Member of the Institution of Civil Engineers, of the French Institution of Civil Engineers, and of other similar societies.

Fig. 1. *Charging Machine.*



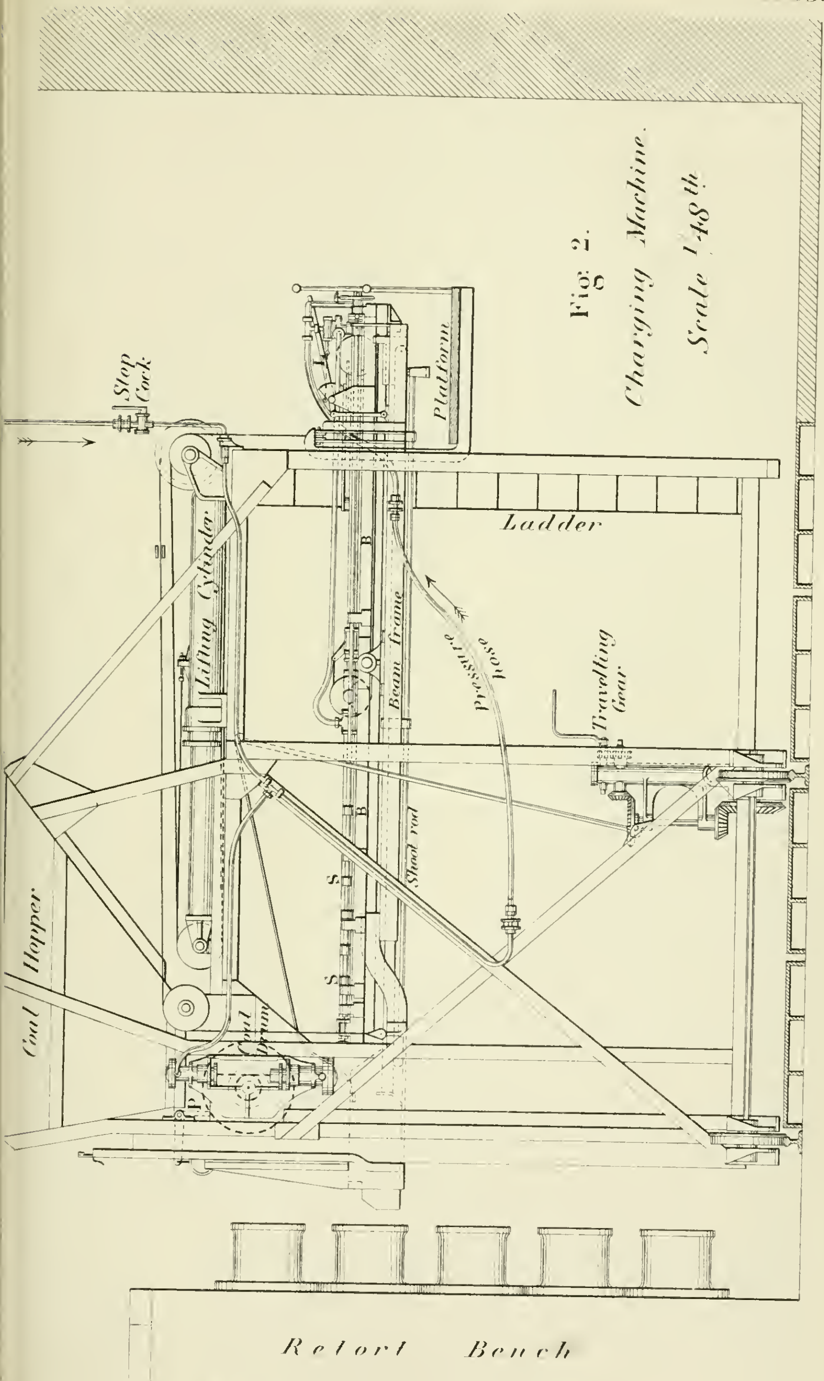
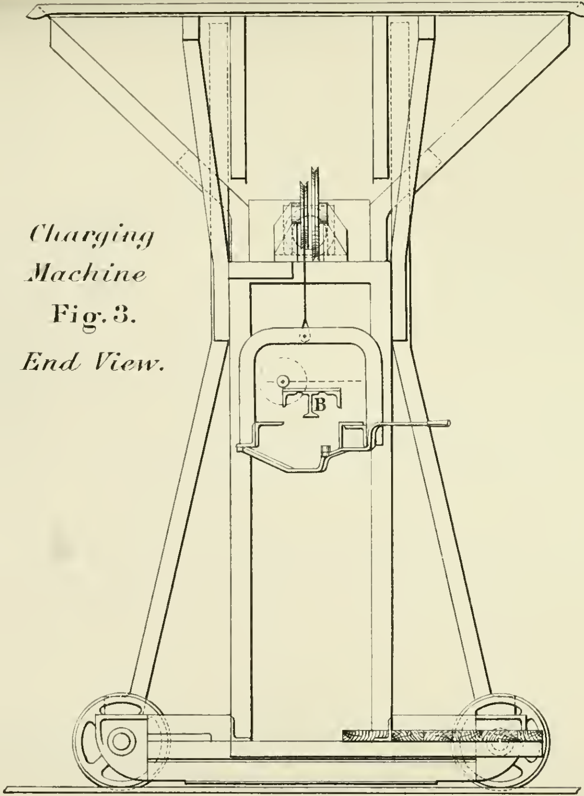


Fig: 2.
Charging Machine.
Scale 1/48th
Stop Cock
Platform
Ladder
Lifting Cylinder
Beam frame
pressure hose
Travelling Gear
Shoot rod
Coal Hopper
Retort Bench

HYDRAULIC GAS-STOKING.



Charging Machine
Fig. 3.
End View.

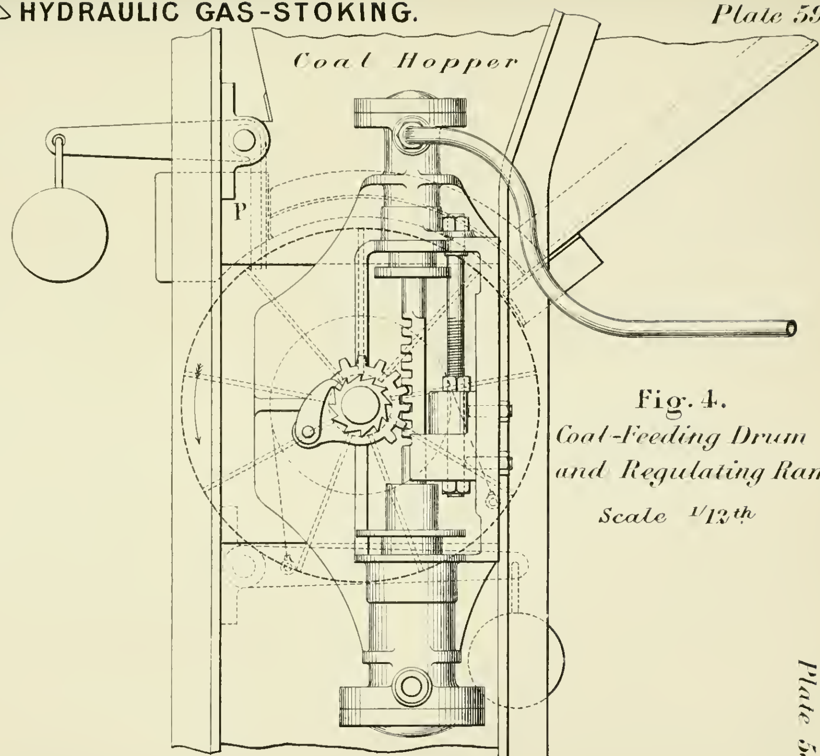


Fig. 4.
Coal-Feeding Drum and Regulating Ram.
Scale 1/12th

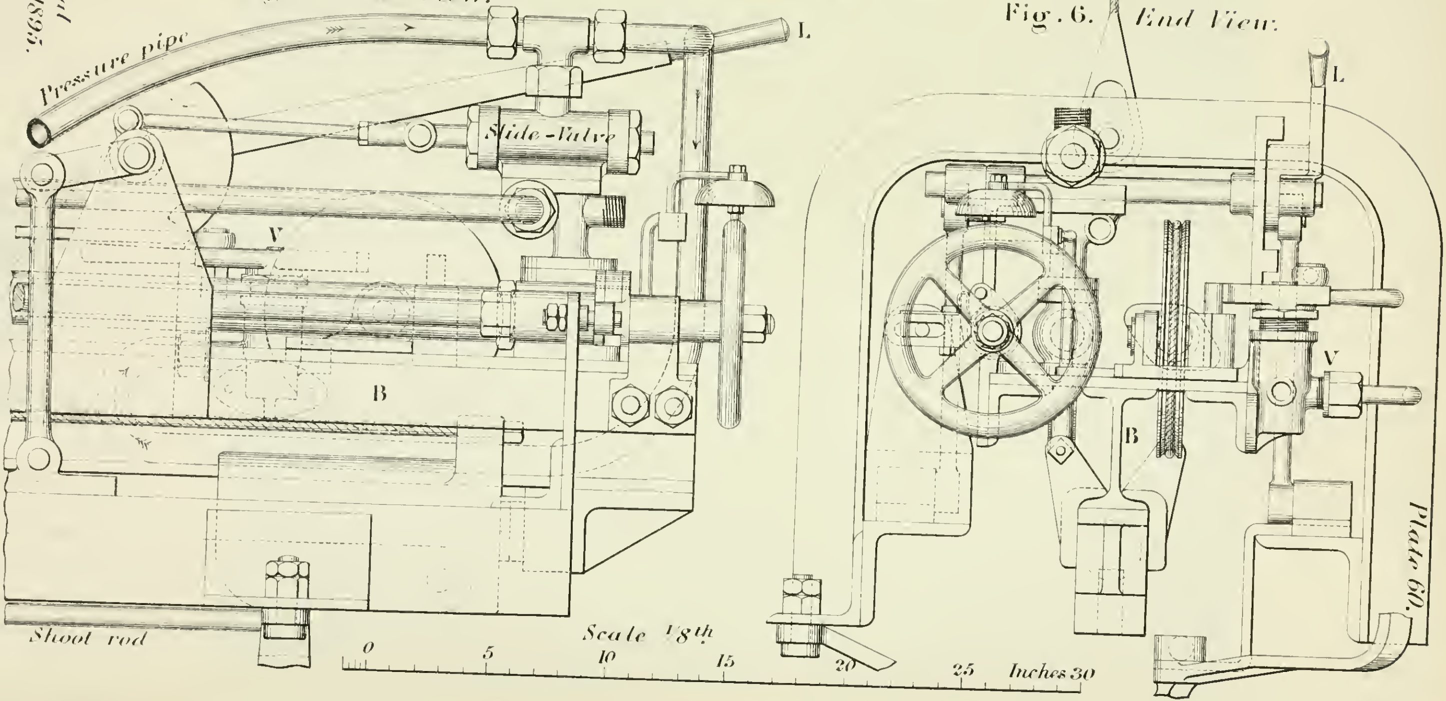
Plate 59.

HYDRAULIC GAS-STOKING.

Detail of Charging Machine.

Outer end of Slide-Beam.

Fig. 5. *Side View.* Fig. 6. *End View.*



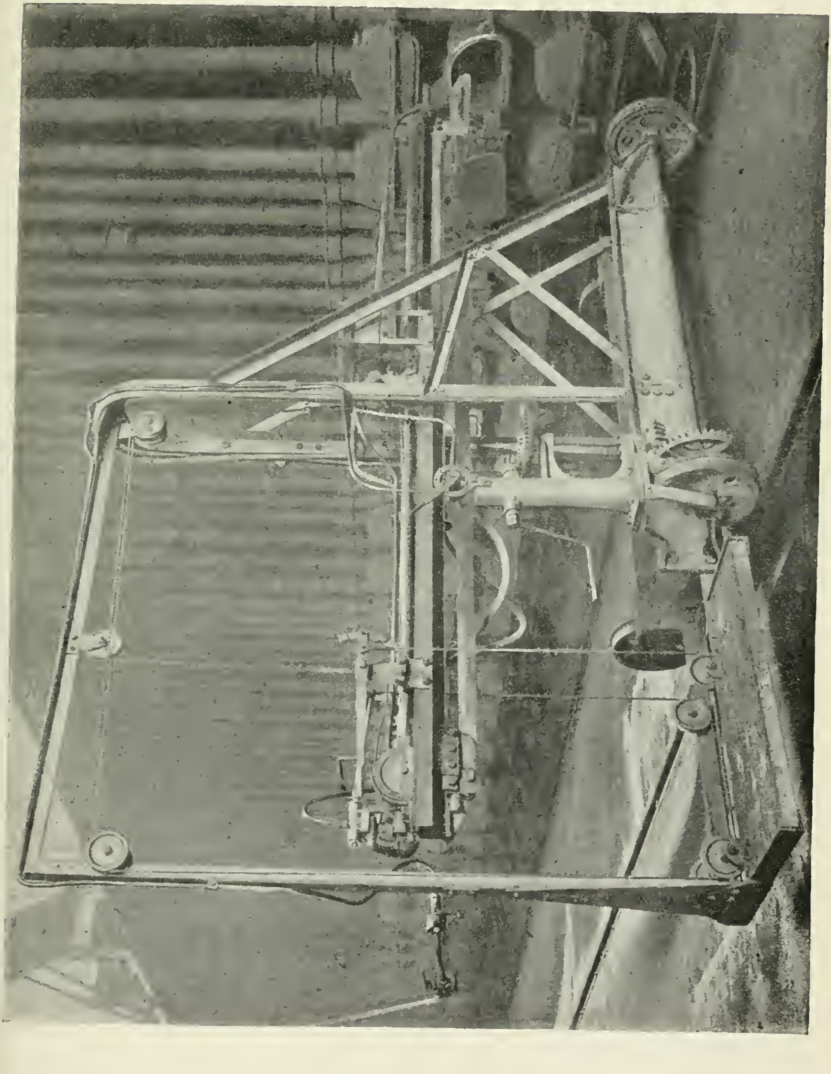


Fig. 7. *Drawing Machine.*

HYDRAULIC GAS-STOKING.

Plate 62.

Fig. 8.

Drawing Machine.

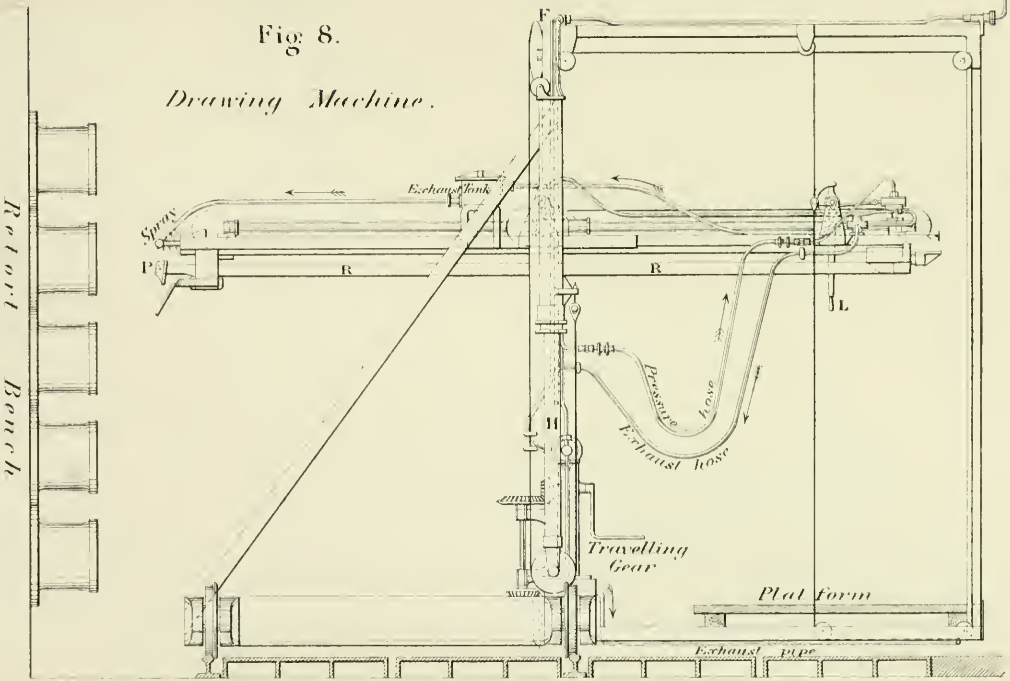
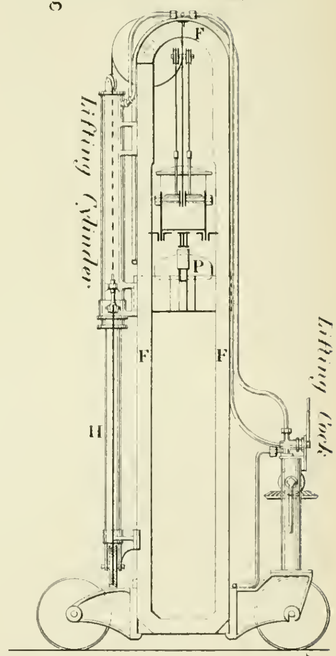


Fig. 9. *End View.*



Scale 1/48th.

Inches 12 6 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 Feet

HYDRAULIC GAS-STOKING.

Details of Drawing-Machine.

Scale 1/16th

Fig: 10. *Side View.*

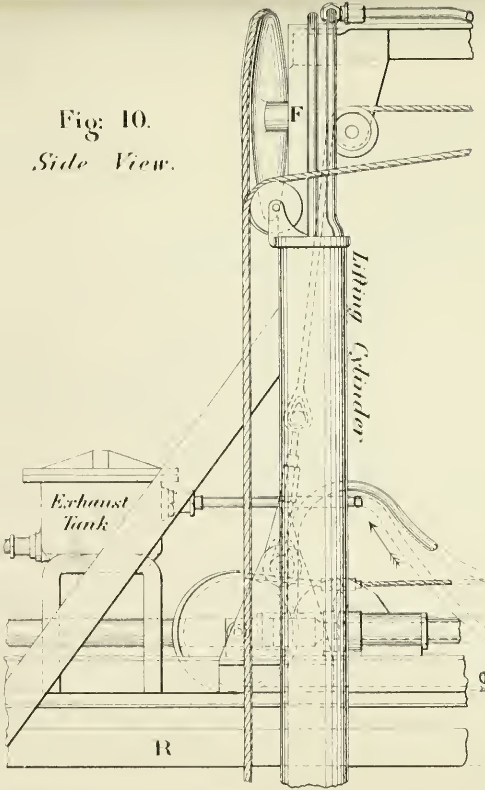


Fig: 11. *Outer end of Slide-Beam.*

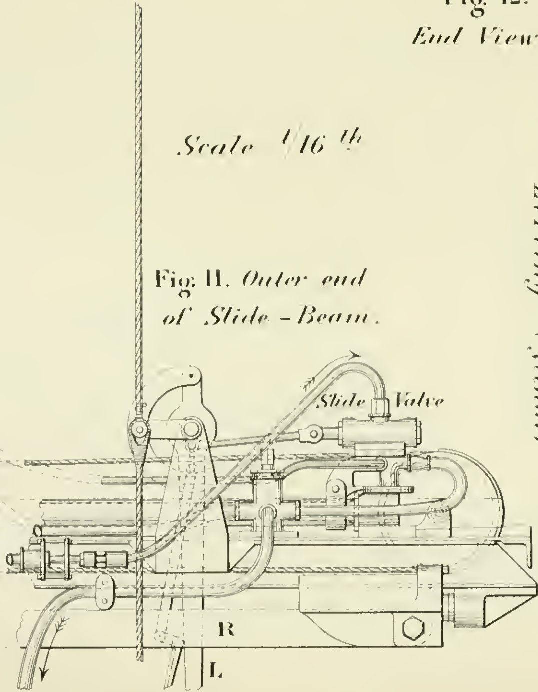


Fig: 12. *End View.*

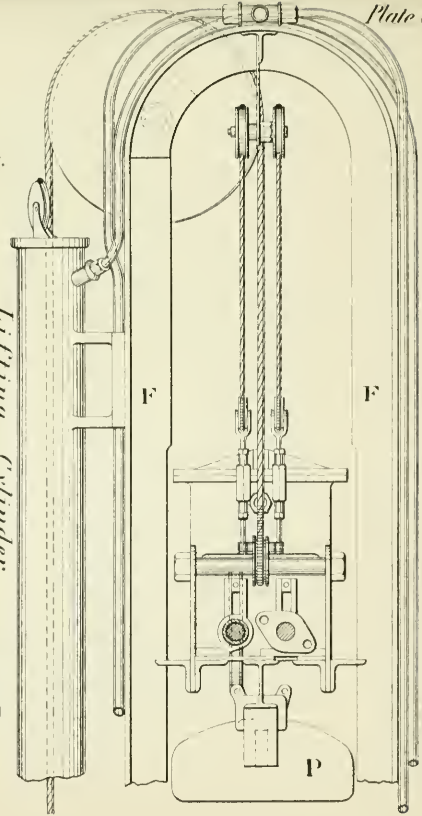
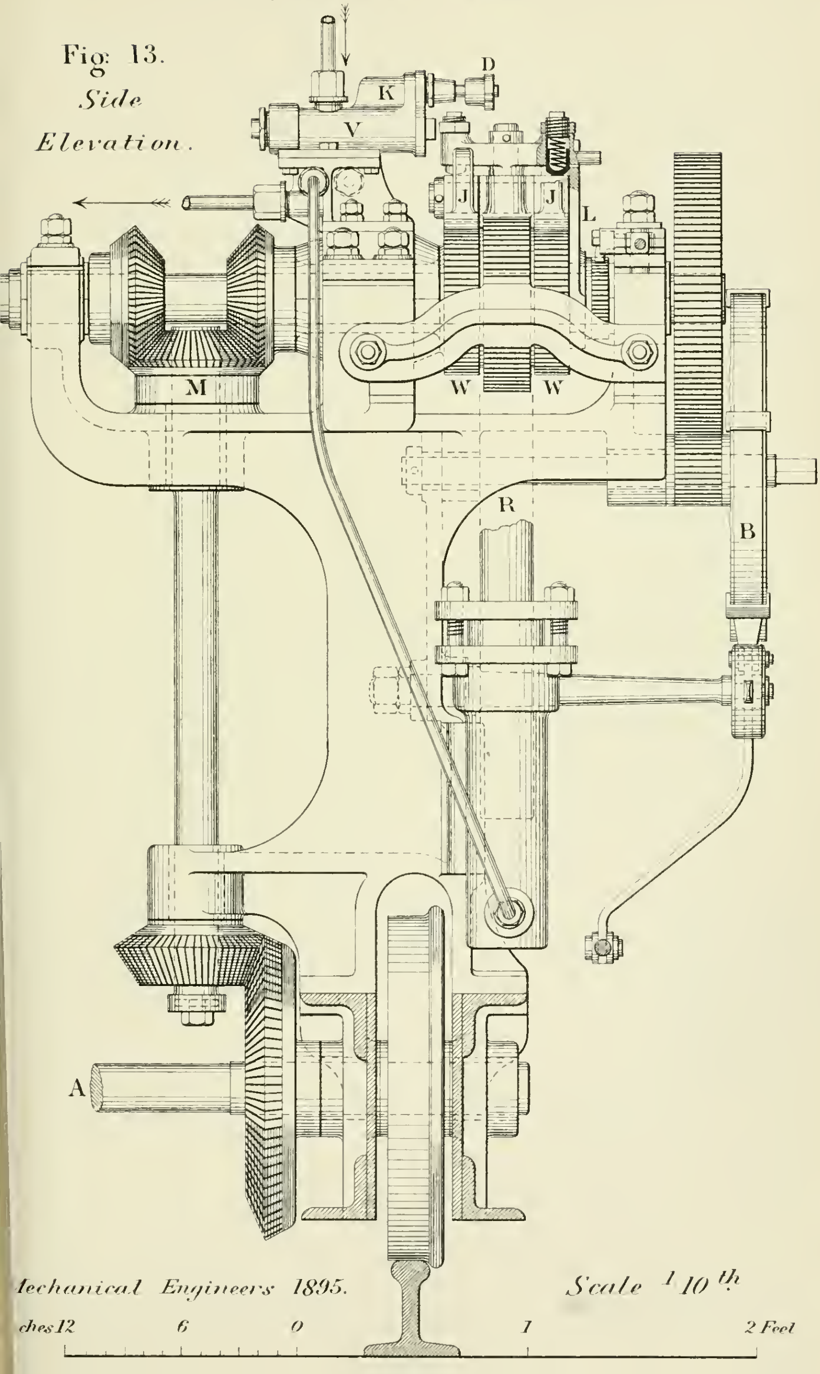


Plate 63.

Hydraulic Motor.

Fig: 13.
Side Elevation.



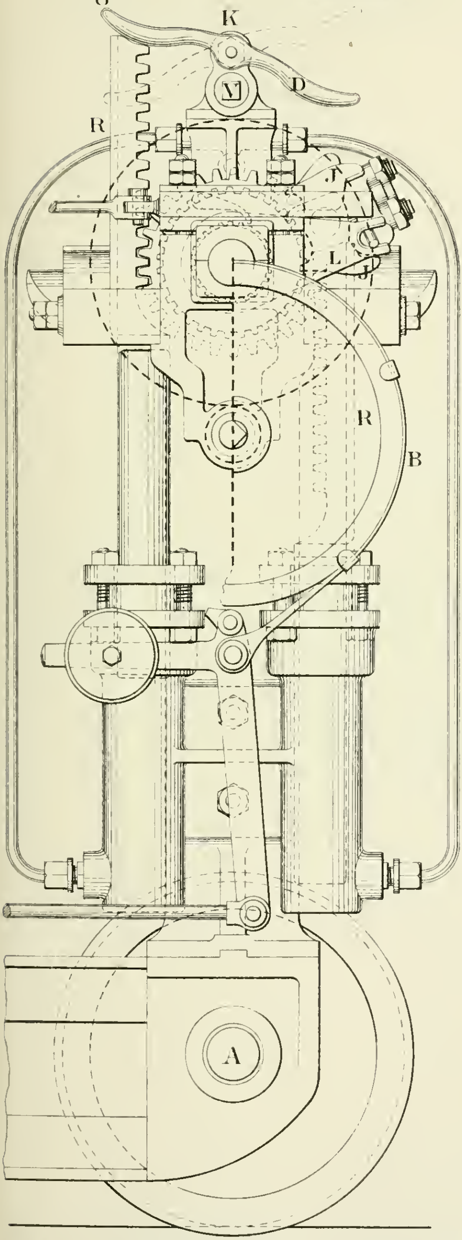
Scale 1/10 th.

Inches 12 6 0 1 2 Feet

HYDRAULIC GAS-STOKING. *Plate 65.*

Hydraulic Motor.

Fig: 14. *End Elevation.*



Reversing Gear.

Fig: 15.

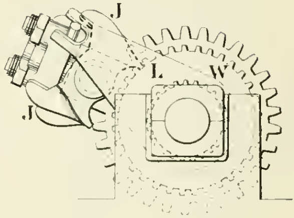


Fig: 16.

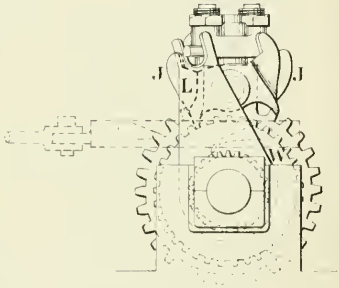
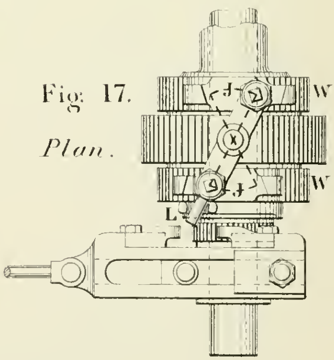


Fig: 17.

Plan.



Mechanical Engineers 1895.

Scale 1/10th

Inches 12 6 0 1 2 Feet

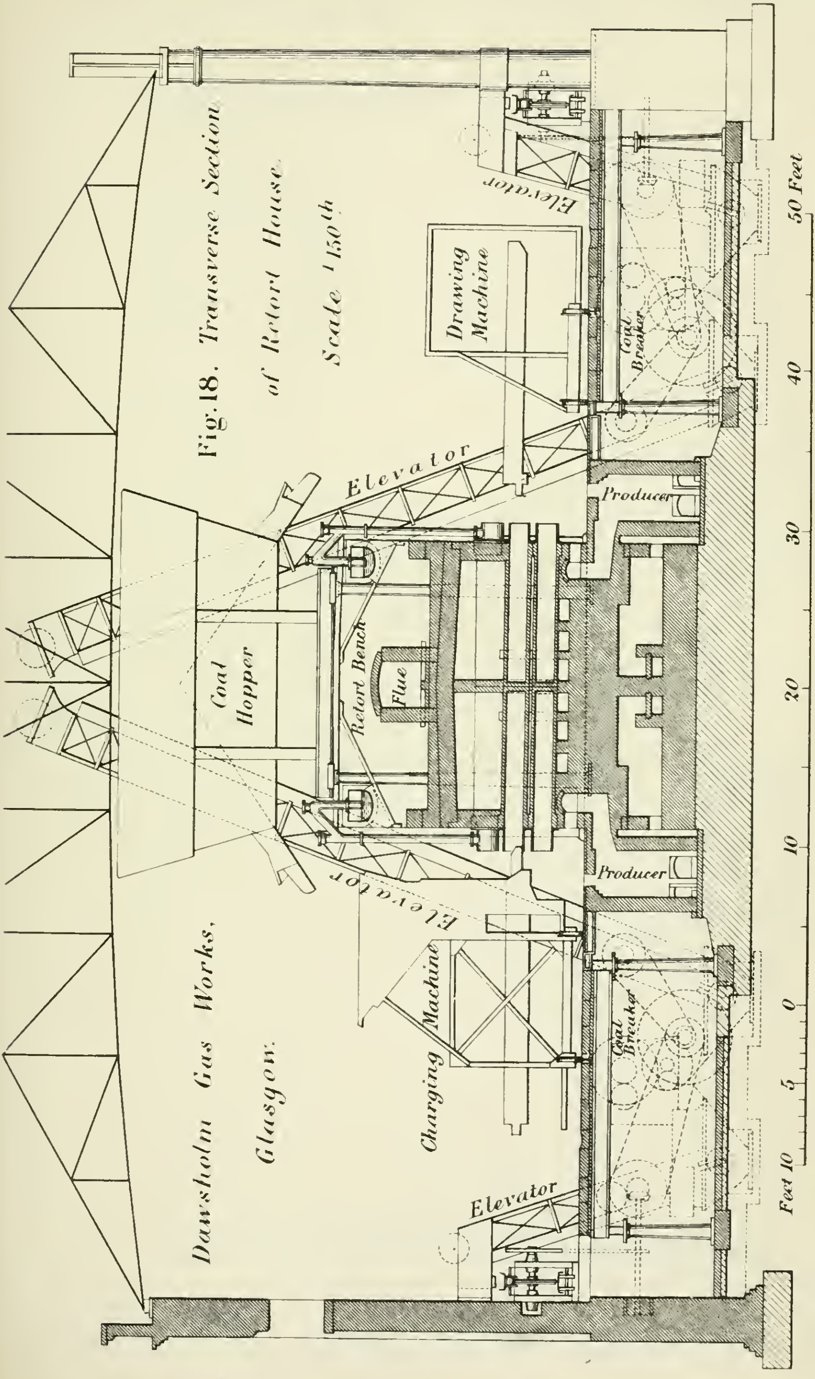
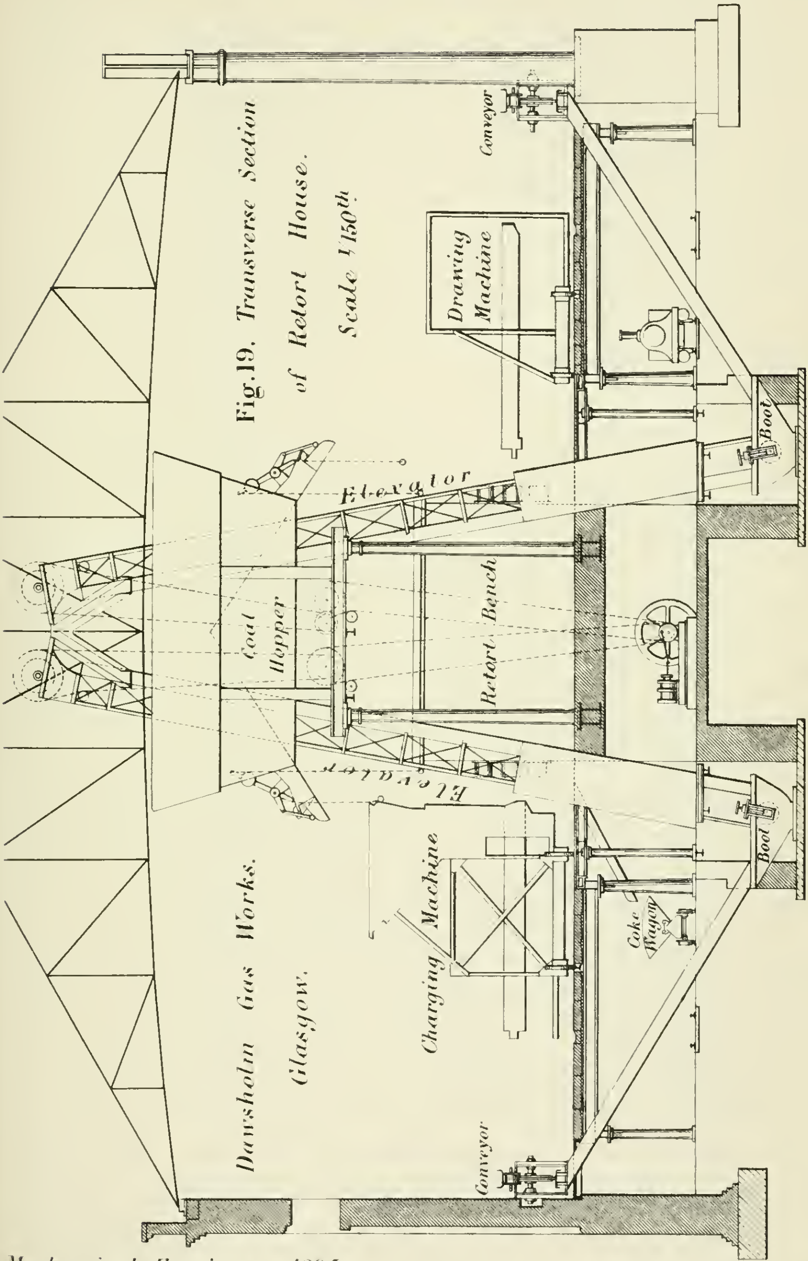


Fig. 18. Transverse Section
of Retort House
Scale 1/150th
Dawsholm Gas Works,
Glasgow.
Elevator
Elevator
Elevator
Elevator
Drawing Machine
Charging Machine
Coal Breaker
Coal Breaker
Producer
Producer
Coal Hopper
Retort Bench
Flue
50 Feet
40
30
20
10
0
5
Feet 10



Mechanical Engineers 1895.

Ft. 10 — 5 — 0 — 10 — 20 — 30 — Feet 40

HYDRAULIC GAS-STOKING.

Birmingham Gas Works.

Fig. 20. *Transverse Section.*

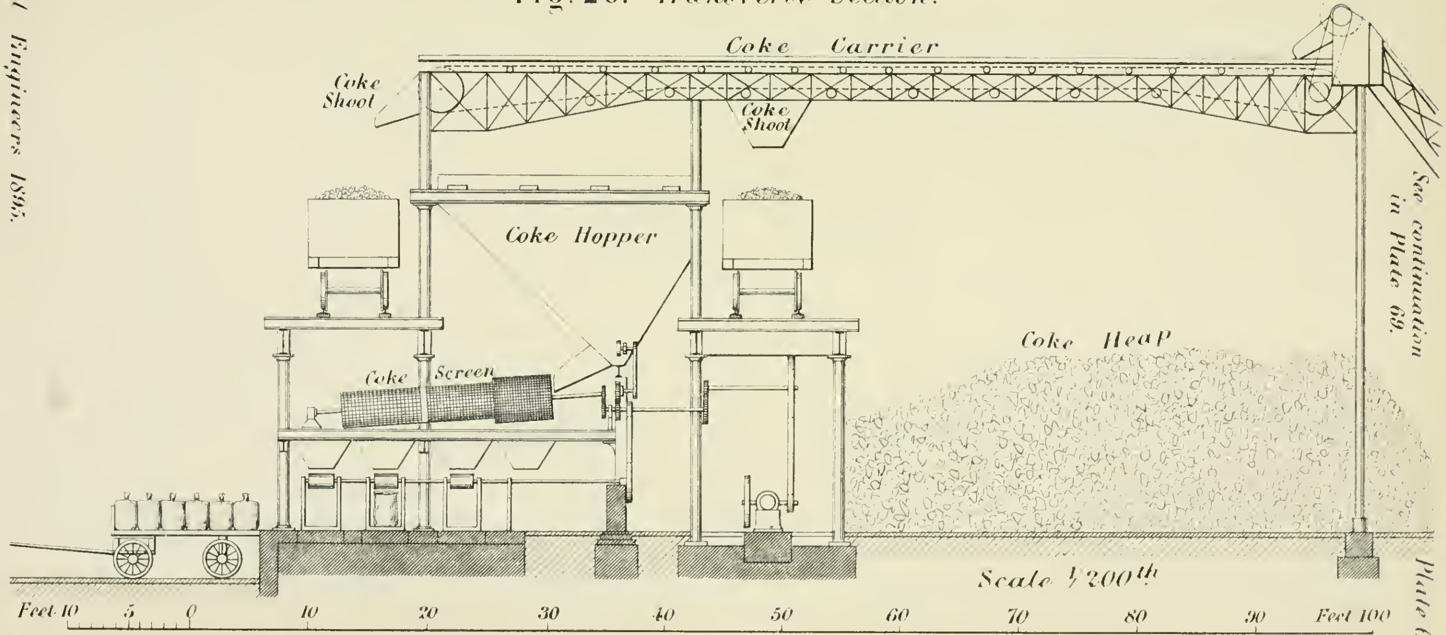
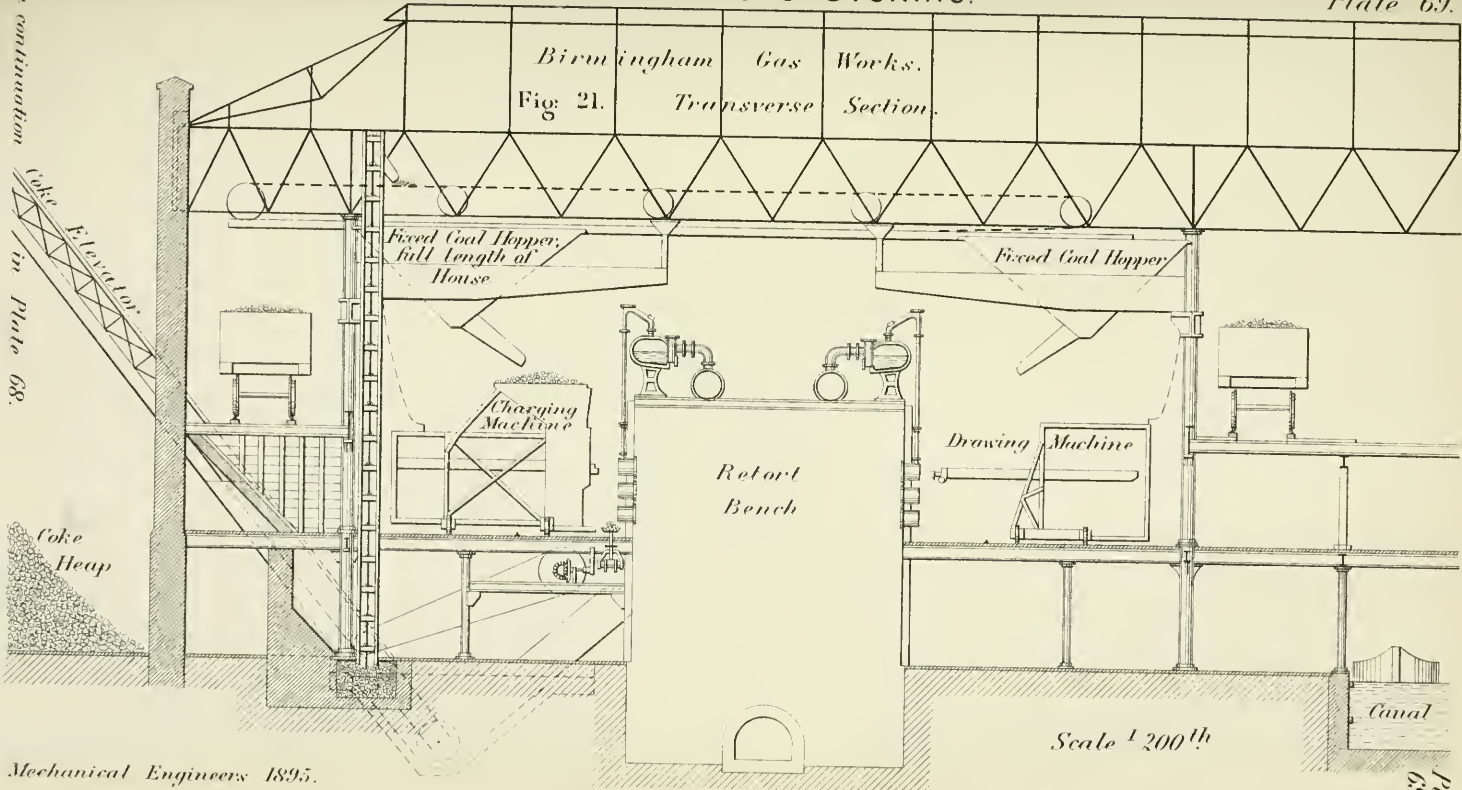


Plate 68.

HYDRAULIC GAS-STOKING.

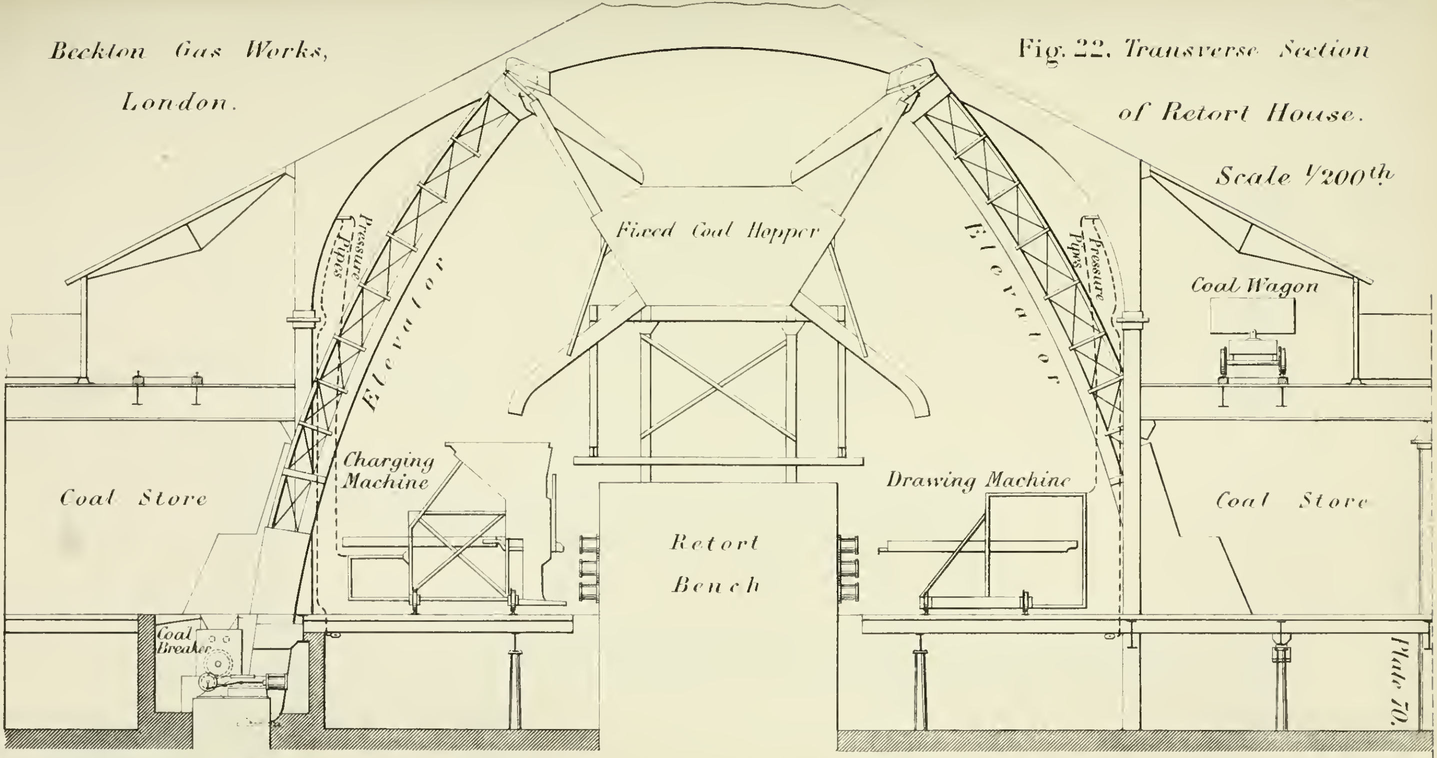
See continuation in Plate 68.



Beckton Gas Works, London.

Fig. 22. Transverse Section of Retort House.

Scale 1/200th.



HYDRAULIC GAS-STOKING.

Vienna Gas Works.

Fig. 23. Transverse Section of Retort House.

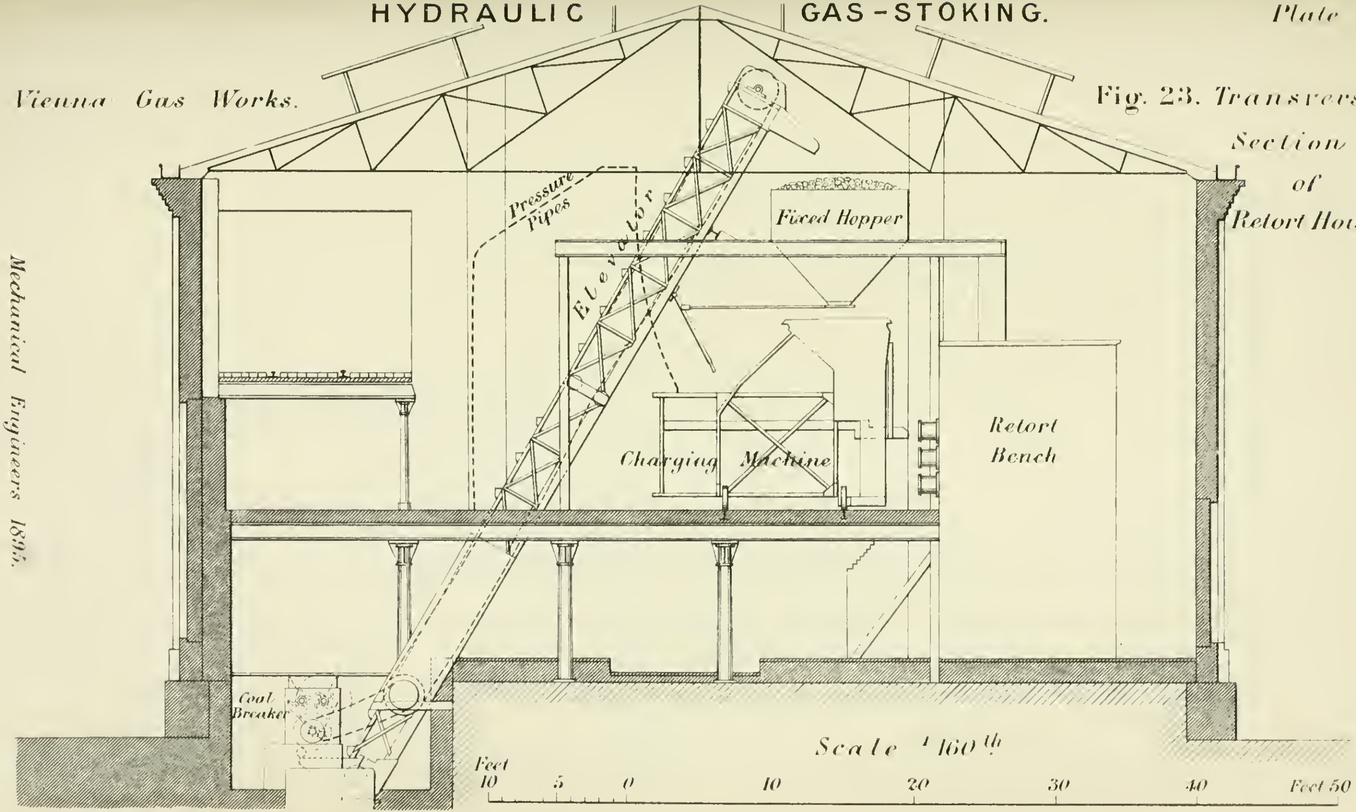
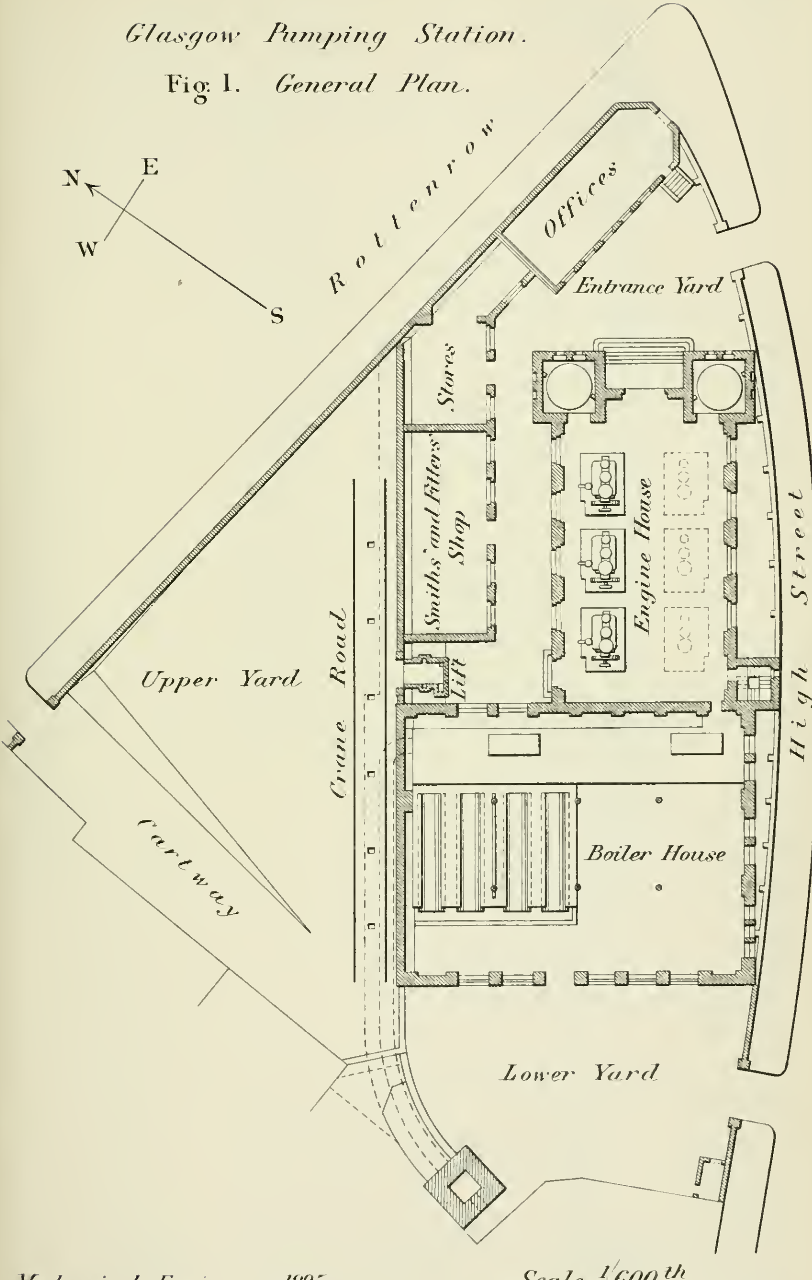


Plate 71.

Glasgow Pumping Station.

Fig. 1. *General Plan.*



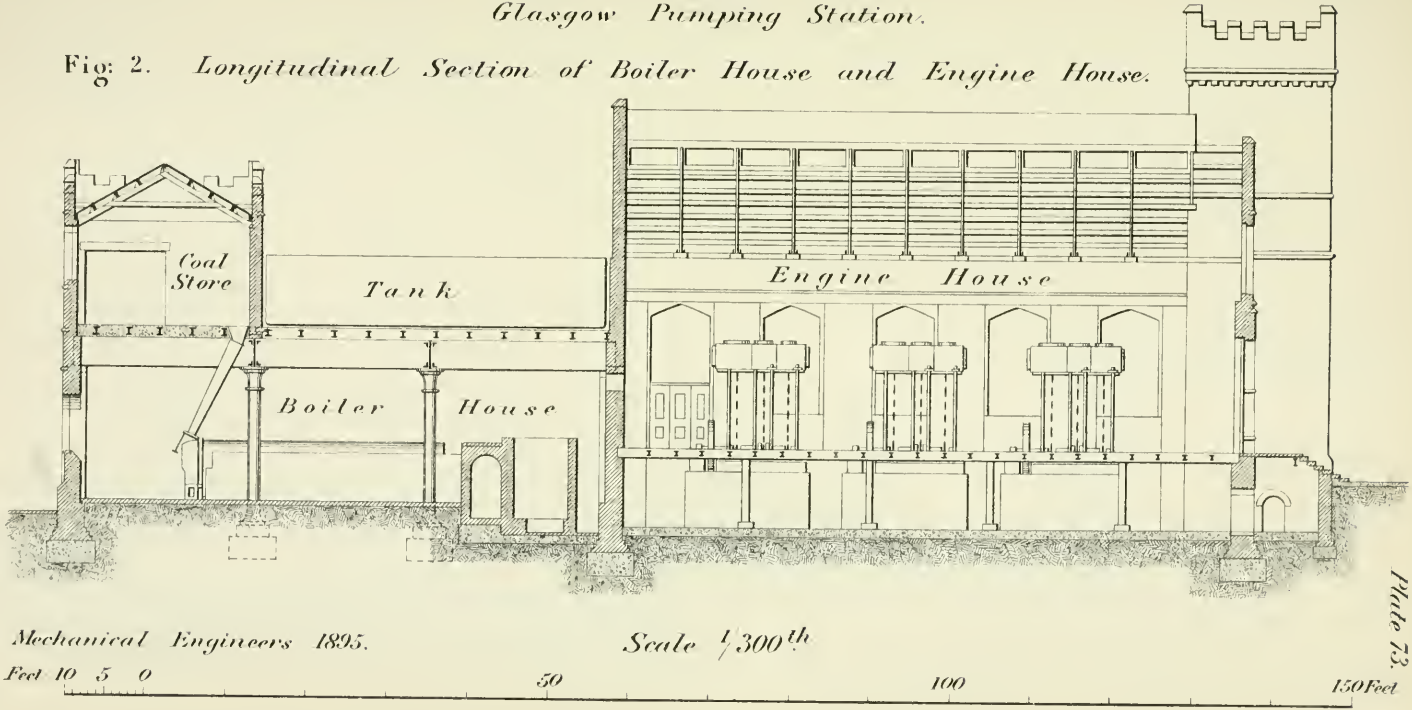
Scale 1/600th

Feet 10 0 50 100 150 Feet

HYDRAULIC POWER SUPPLY.

Glasgow Pumping Station.

Fig: 2. Longitudinal Section of Boiler House and Engine House.



Mechanical Engineers 1895.

Scale 1/300th

Plate 73.

HYDRAULIC POWER SUPPLY.

Glasgow Pumping Station.

Fig. 3. *Transverse Section of Engine House.*

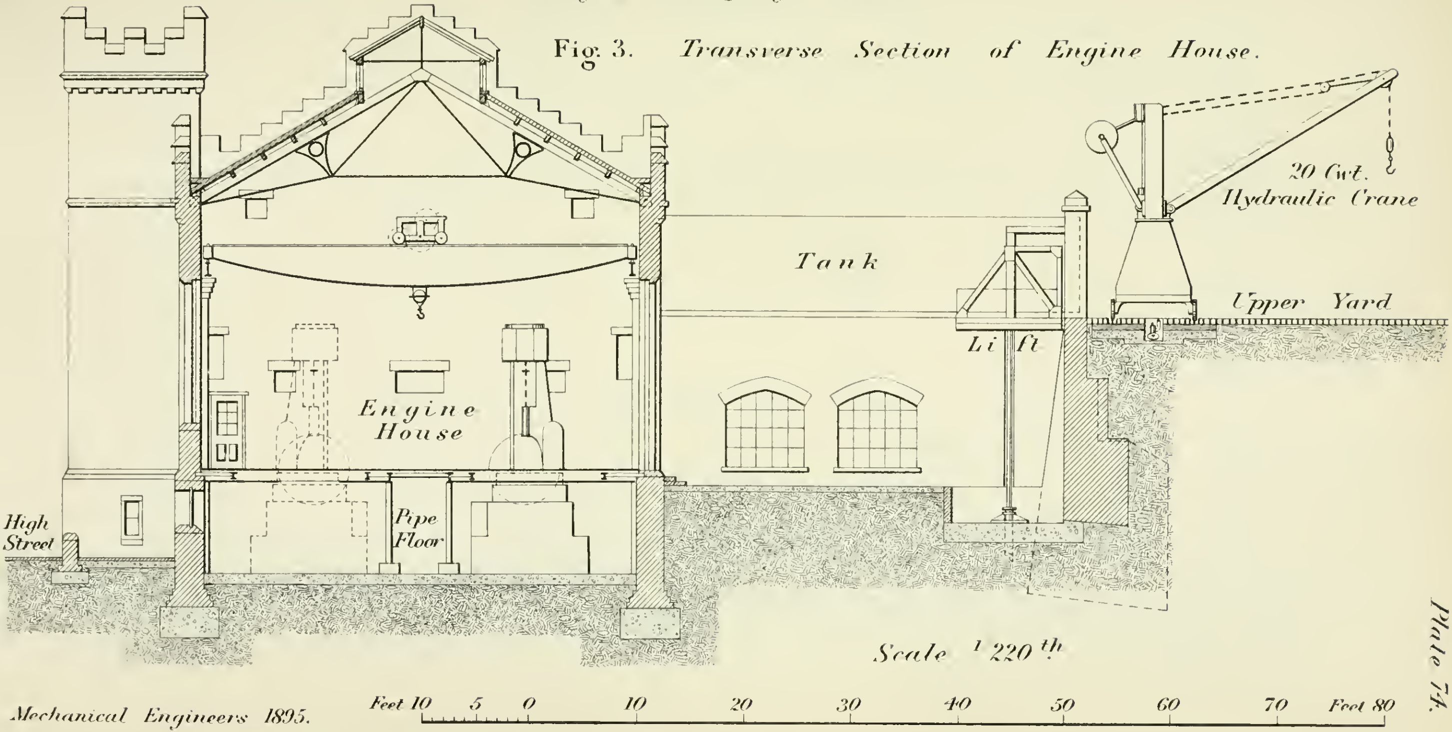
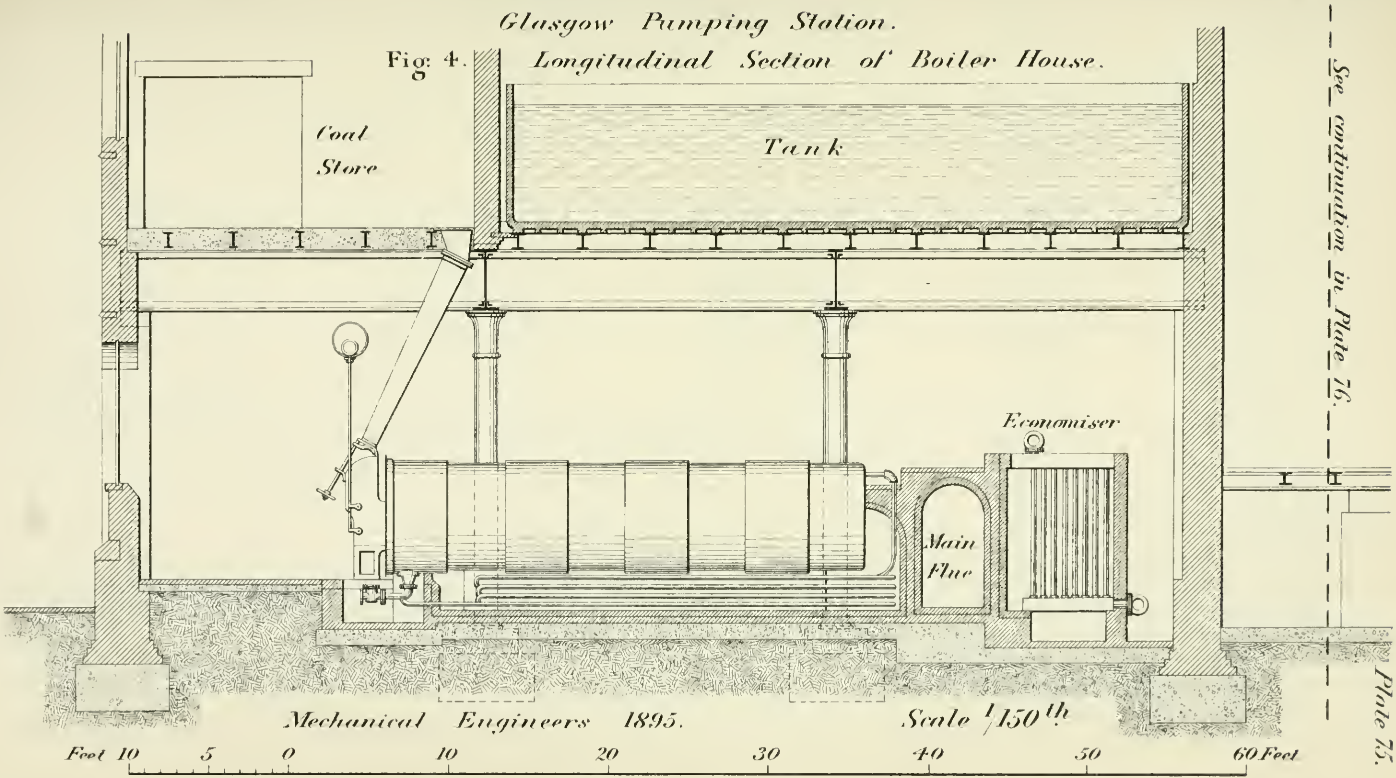


Plate 74.

Glasgow Pumping Station.

Fig: 4. Longitudinal Section of Boiler House.



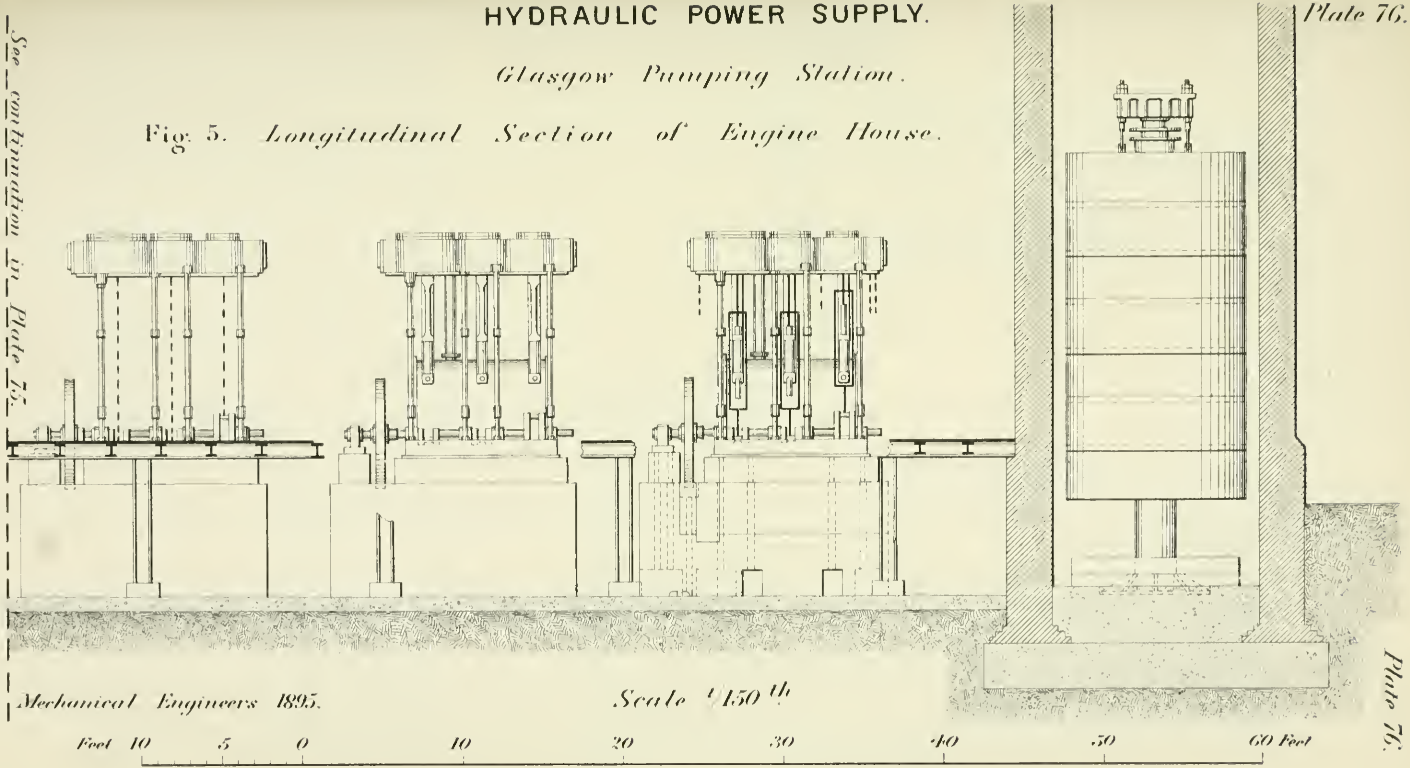
Mechanical Engineers 1895. Scale 1/150th.

Plate 75.

HYDRAULIC POWER SUPPLY.

Glasgow Pumping Station.

Fig. 5. *Longitudinal Section of Engine House.*



Scale 1/150th.

Plate 76.

Glasgow Pumping Station.
Transverse Sections of Retaining Wall.

Fig: 6.

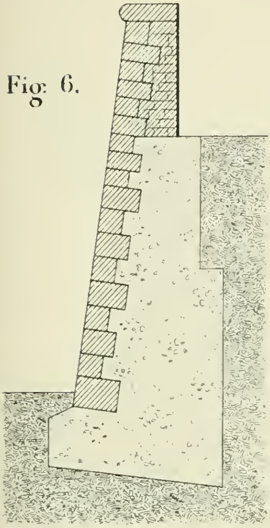
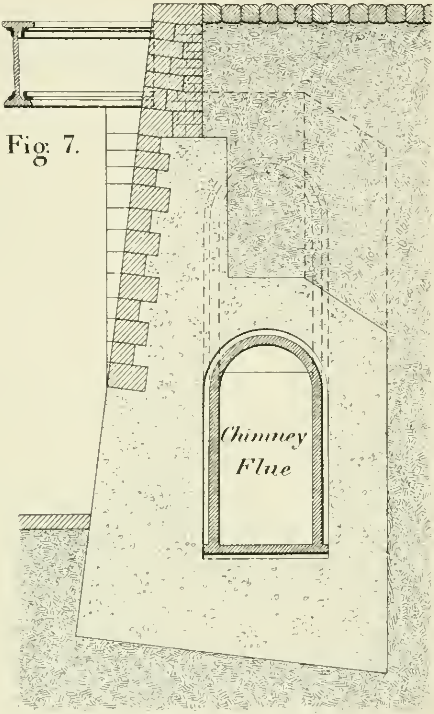
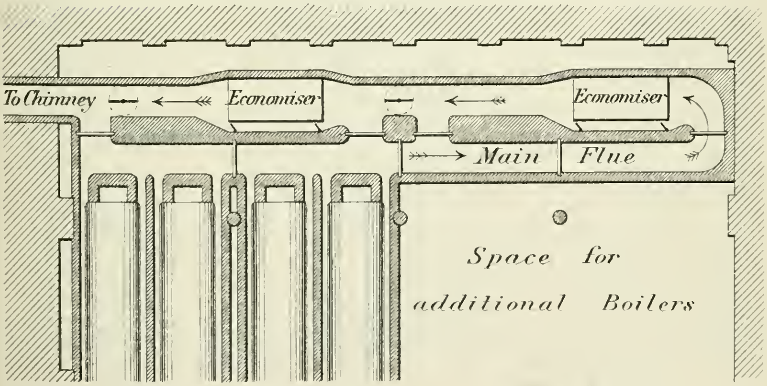


Fig: 7.



Scale 1/100th.

Fig: 8. *Sectional Plan of Main Flue from Boilers.*



Mechanical Engineers 1895. *Scale 1/300th.*

Feet 10 5 0 10 20 30 40 50 60 Feet

Accumulator.

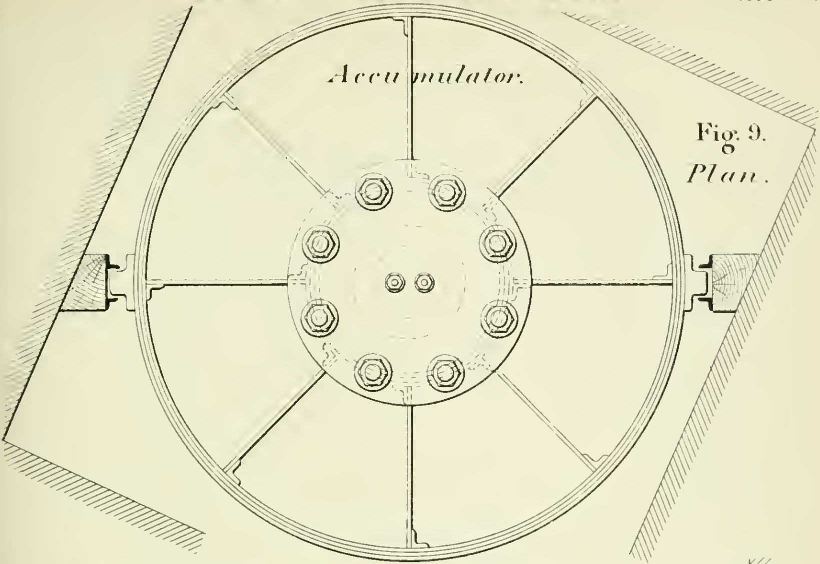


Fig: 9.
Plan.

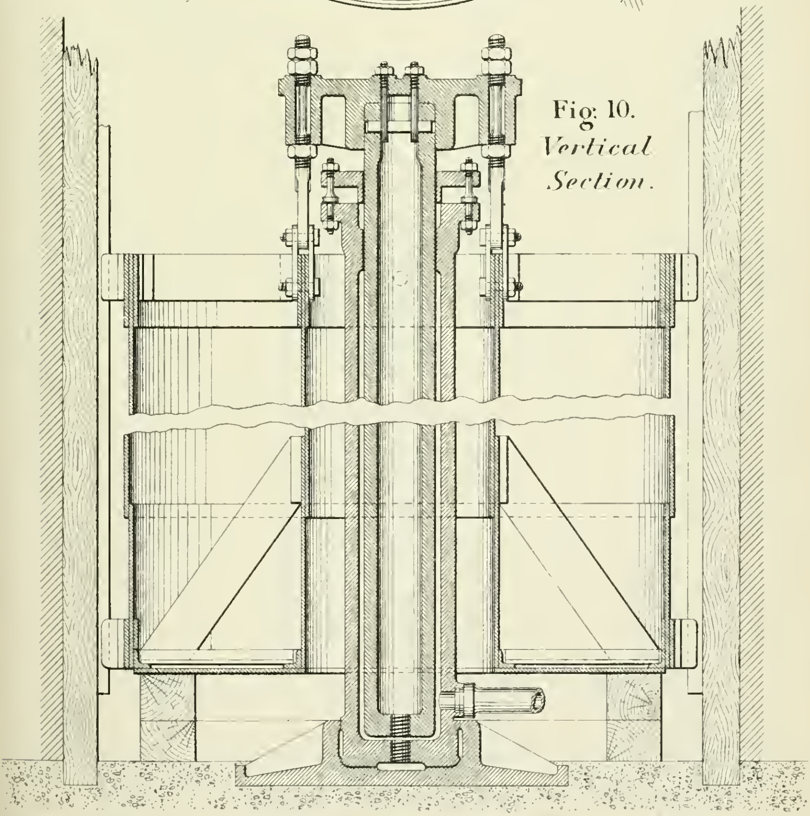
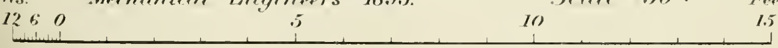


Fig: 10.
Vertical Section.

Scale 1/50th



HYDRAULIC POWER SUPPLY.

Fig. 11. Plan of Glasgow Mains.

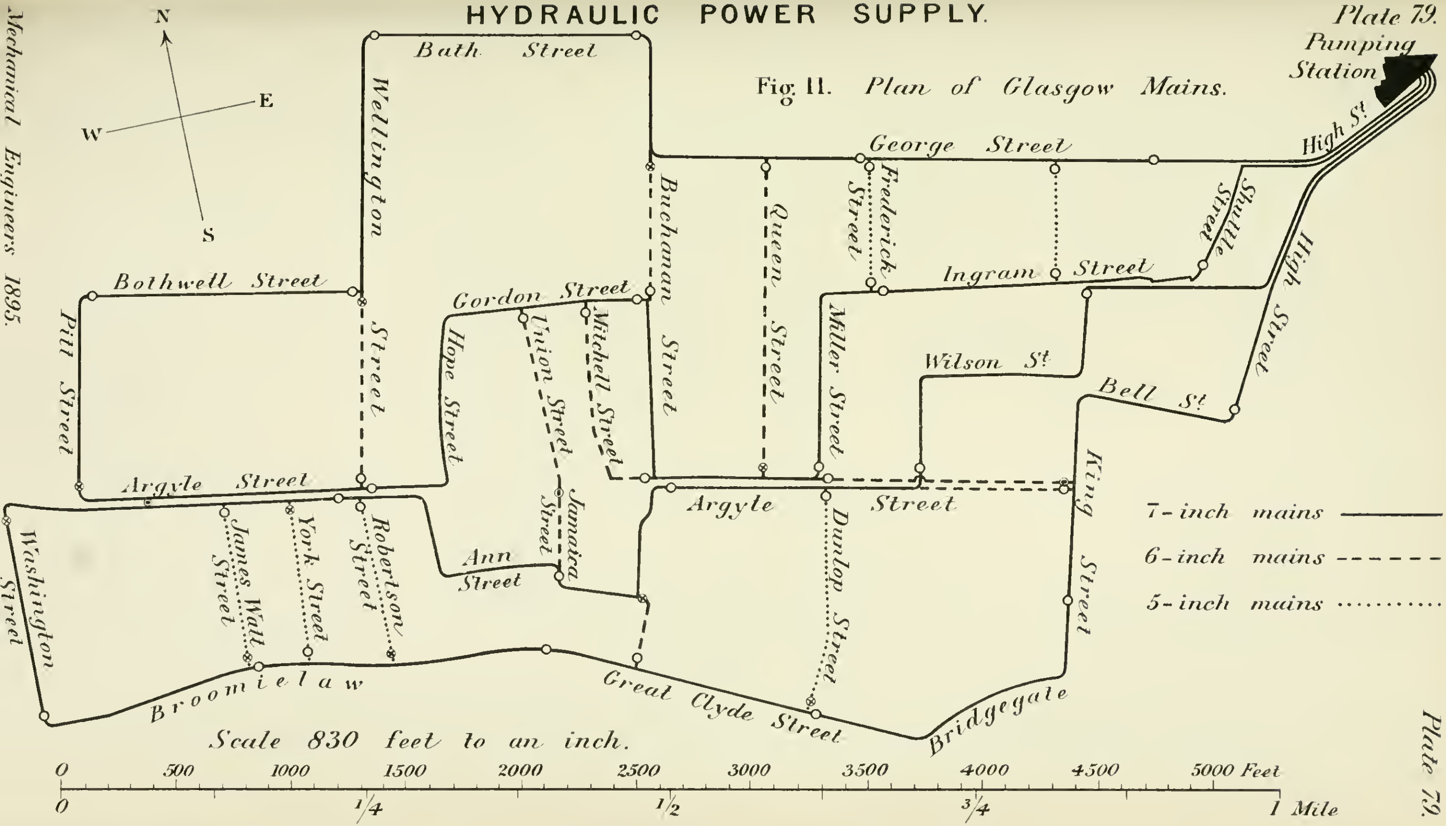


Plate 79.

Valve-Pit for 5, 6, and 7-inch mains.

Fig: 12. *Transverse Section.*

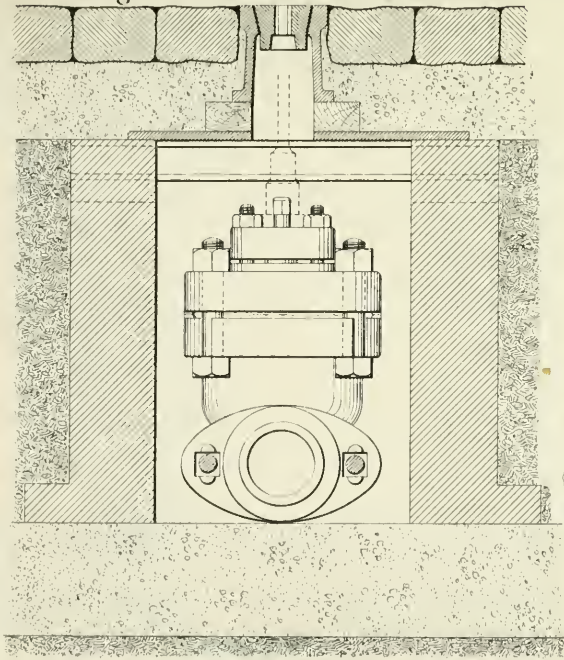


Fig: 13. *Longitudinal Section.*

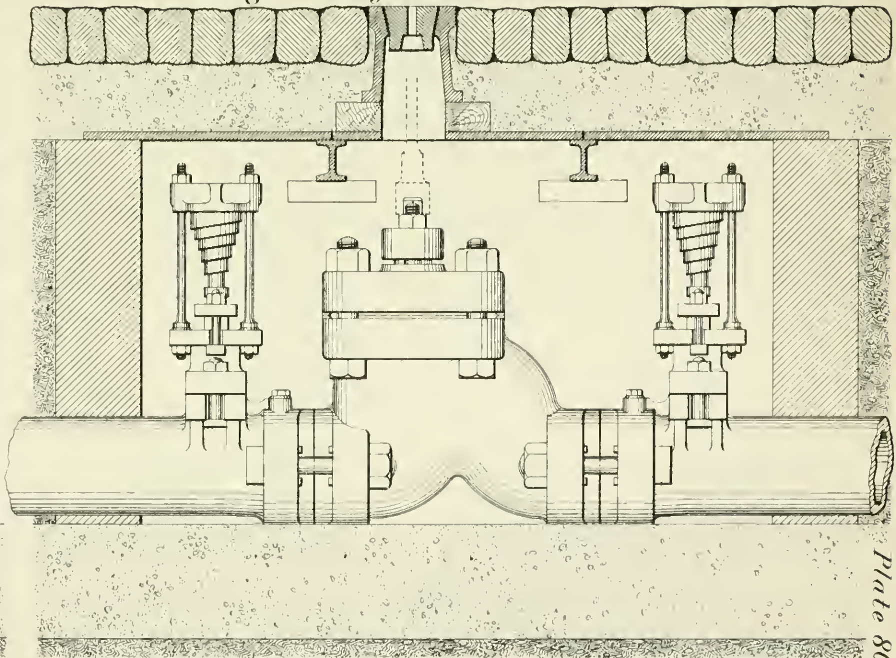


Plate 80.

Ins. 12 6 0 1 2 3 4 5 Feet

Scale 1/20th.

HYDRAULIC POWER SUPPLY.

7-inch Stop-valve.

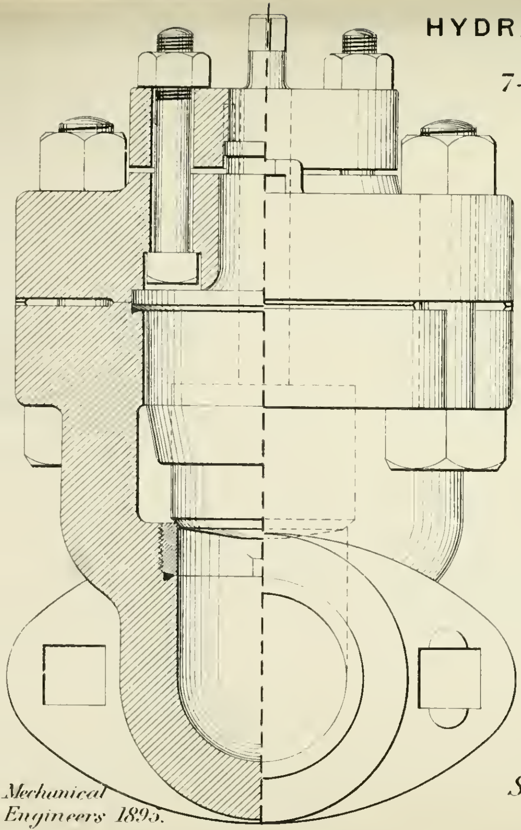


Fig. 14.
Transverse Section and Elevation.

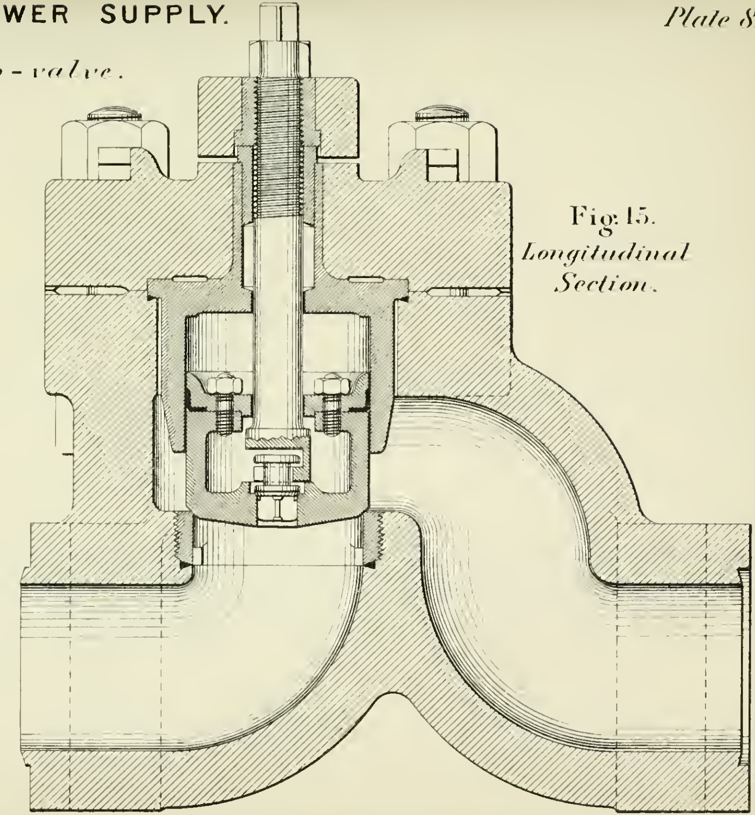


Fig. 15.
Longitudinal Section.

Scale 1/8th

Plate 81.

Standard Pipe.

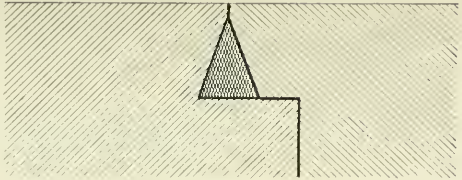


Fig: 18.
Section of Joint.
Full size.

Fig: 16.
End View.

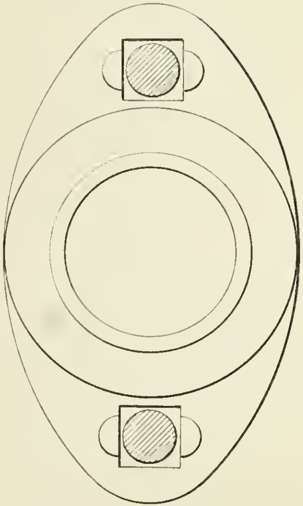
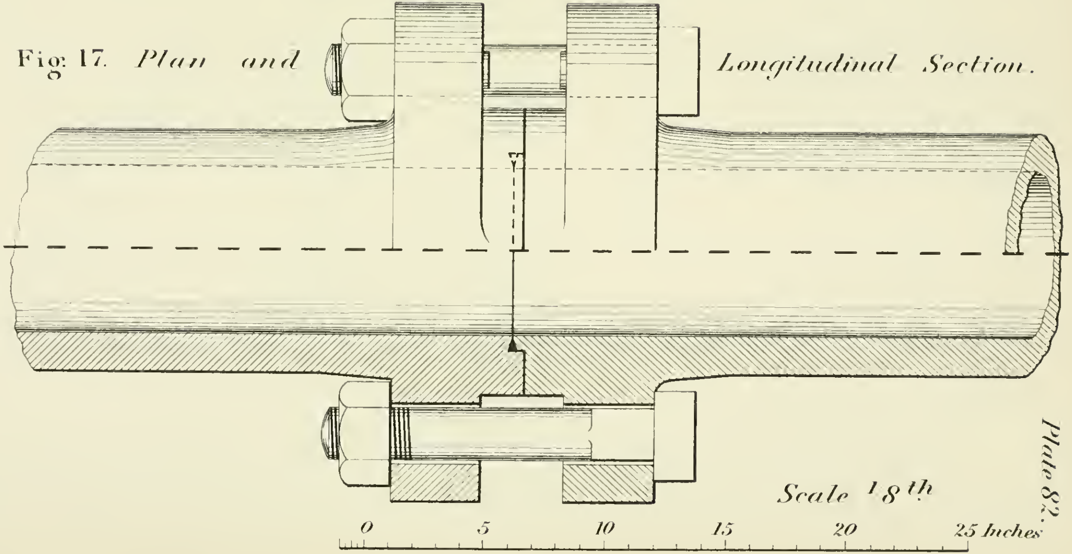


Fig: 17. *Plan and Longitudinal Section.*



Scale 1/8th

Plate 82.

HYDRAULIC POWER SUPPLY.

Automatic Flow-Recorder.

Fig: 19. *Front Elevation.*

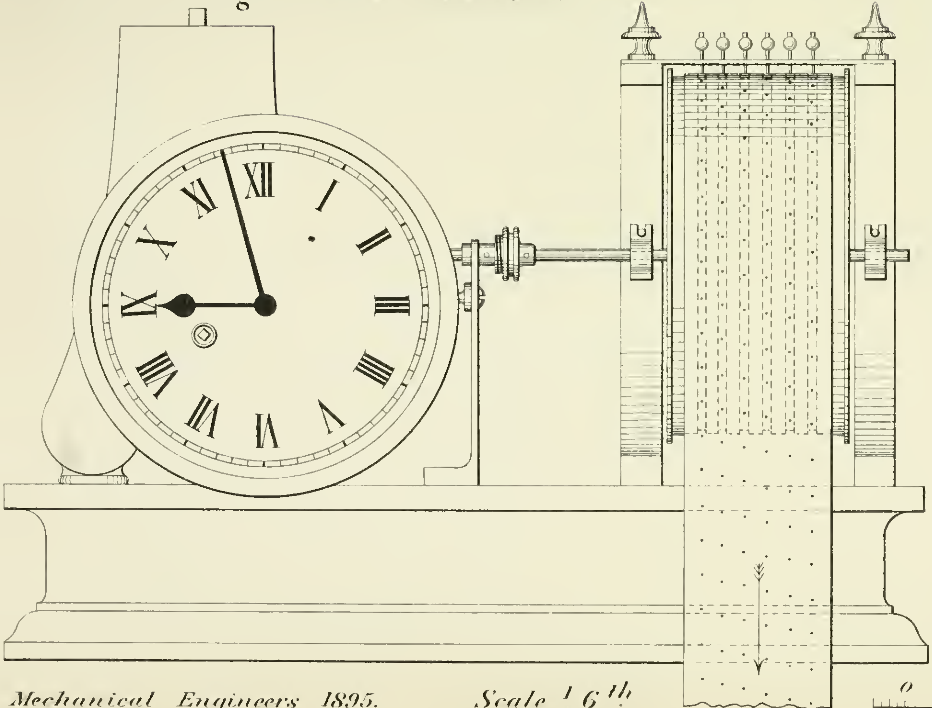
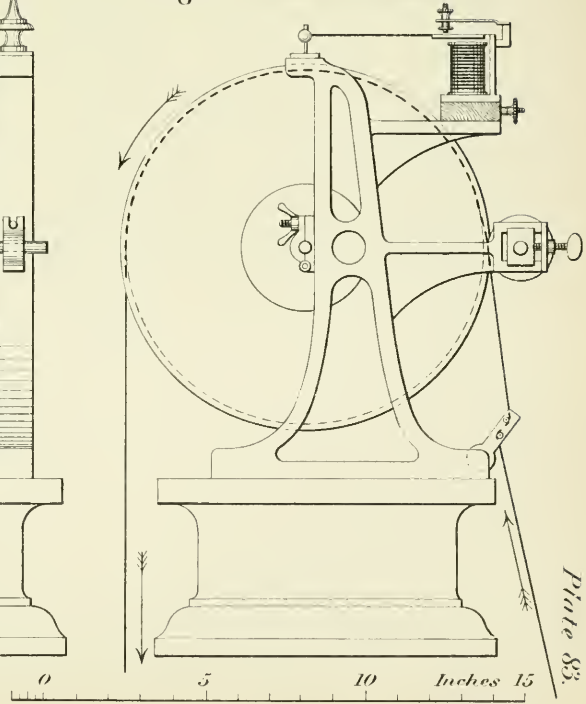


Fig: 20. *End Elevation.*



Scale 1/6th.

Plate 83.

HYDRAULIC POWER SUPPLY.

Parkinson Water Meter.

Fig. 21. Longitudinal Section.

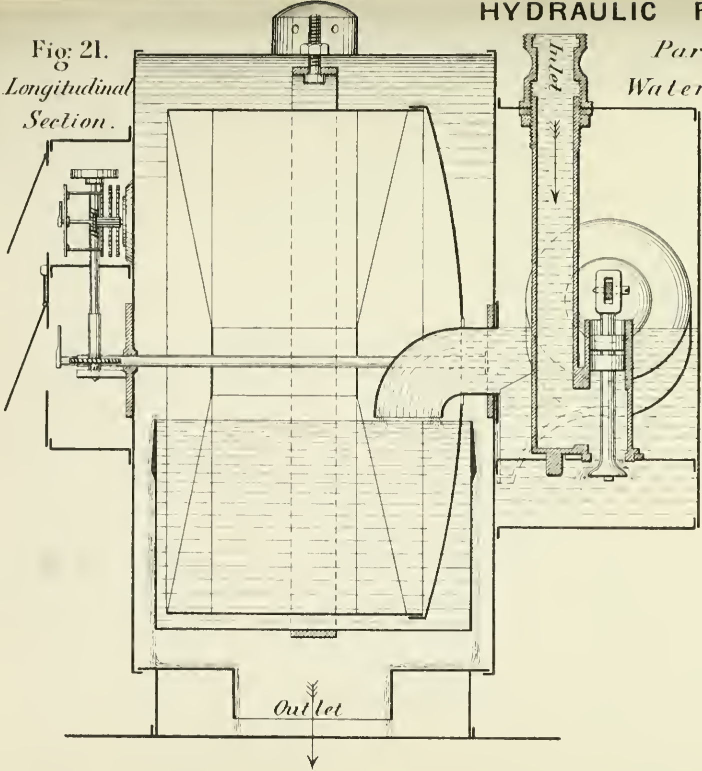
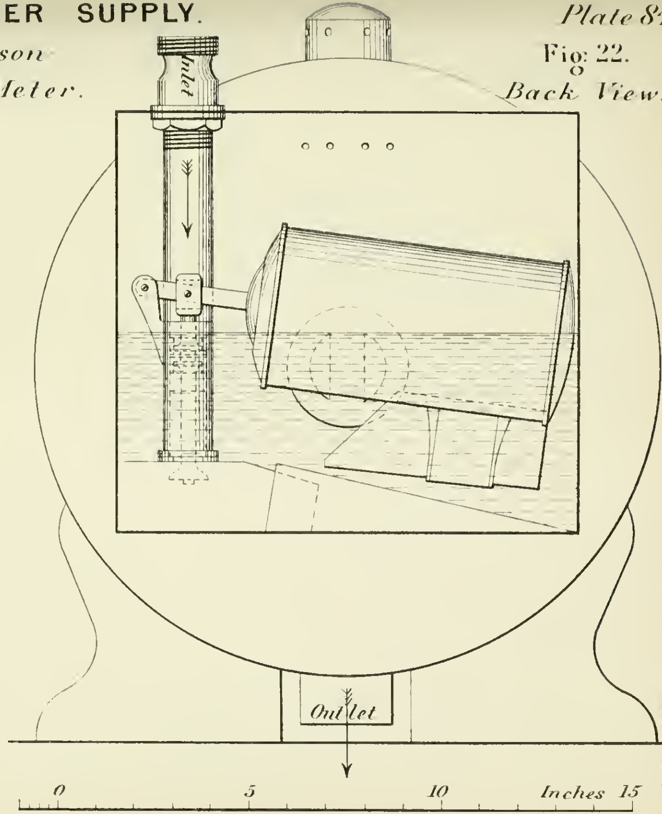


Fig. 22. Back View.



Scale 1/5 th.

Plate 84.

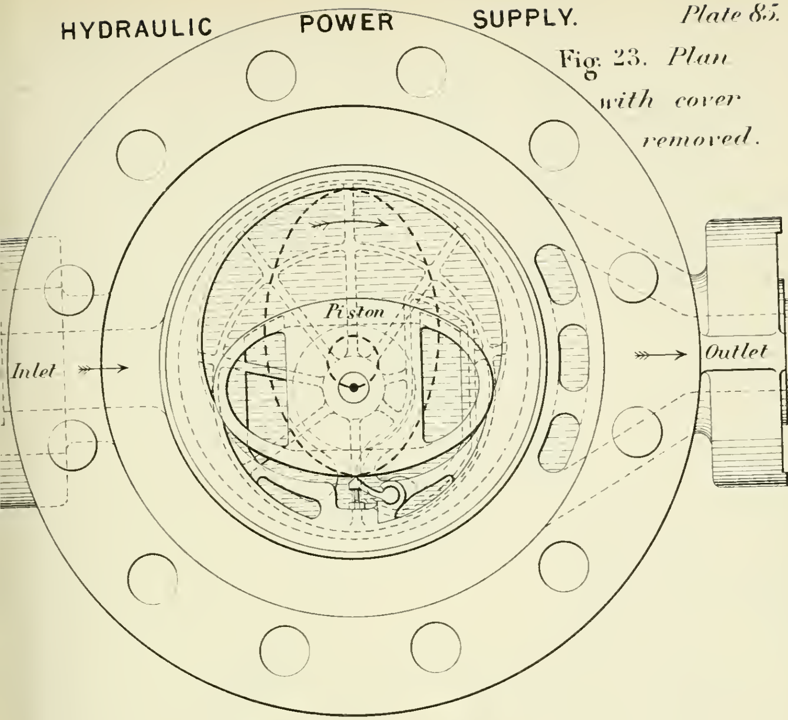


Fig: 23. *Plan with cover removed.*

Kent Water Meter.

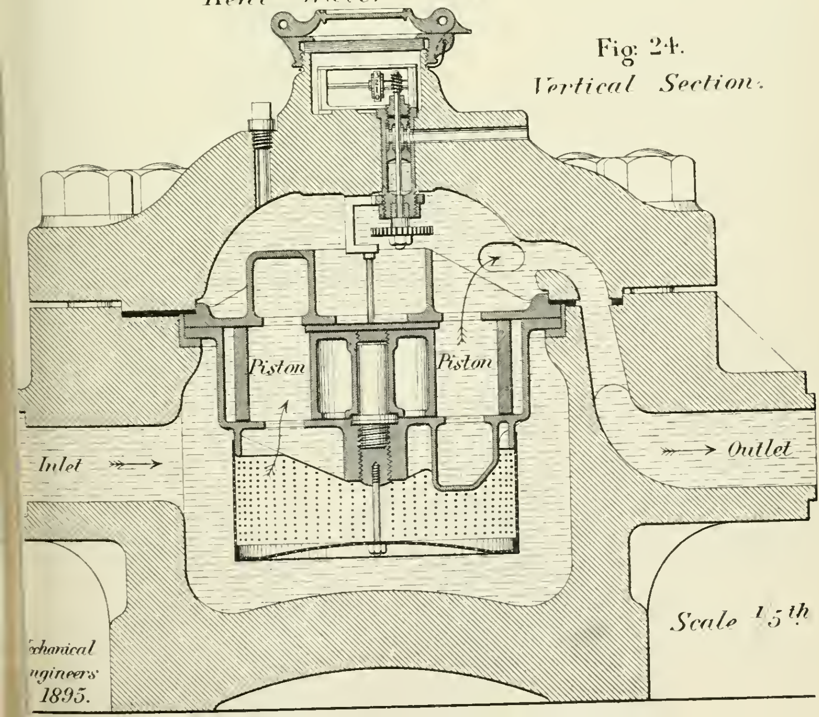


Fig: 24. *Vertical Section.*

Scale 1/5th

HYDRAULIC POWER SUPPLY.

Pelton Motor driving Dynamo.

Fig: 25. *Side Elevation.*

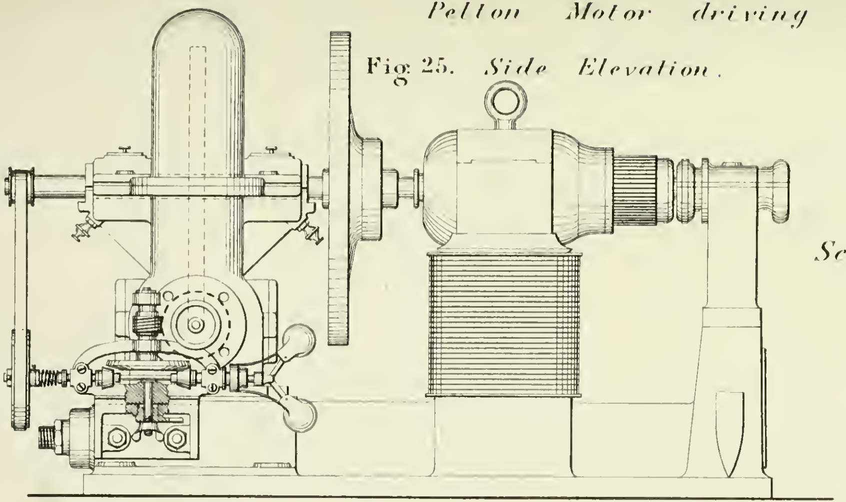
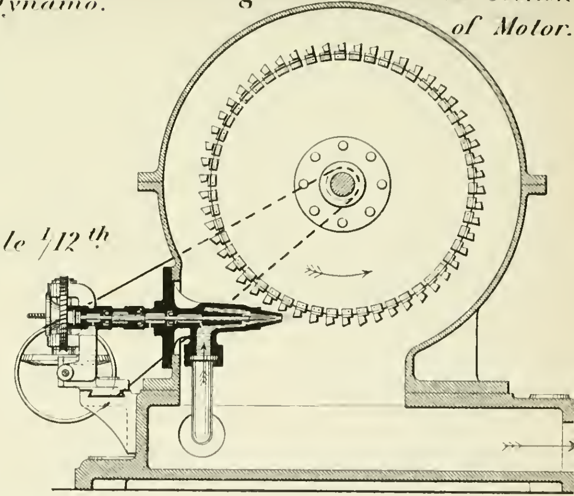


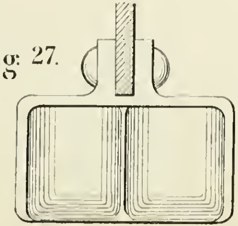
Fig: 26. *Transverse Section of Motor.*



Scale 1/12th.

Full-size views of Buckets.

Fig: 27.



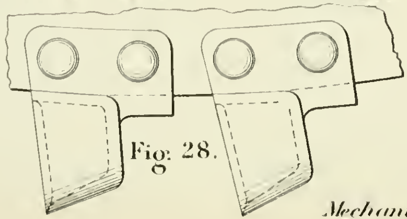


Fig: 28.

Fig: 29.

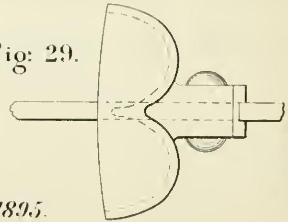


Fig. 30. *Maximum Days of Pumping. London Hydraulic Power Supply.*

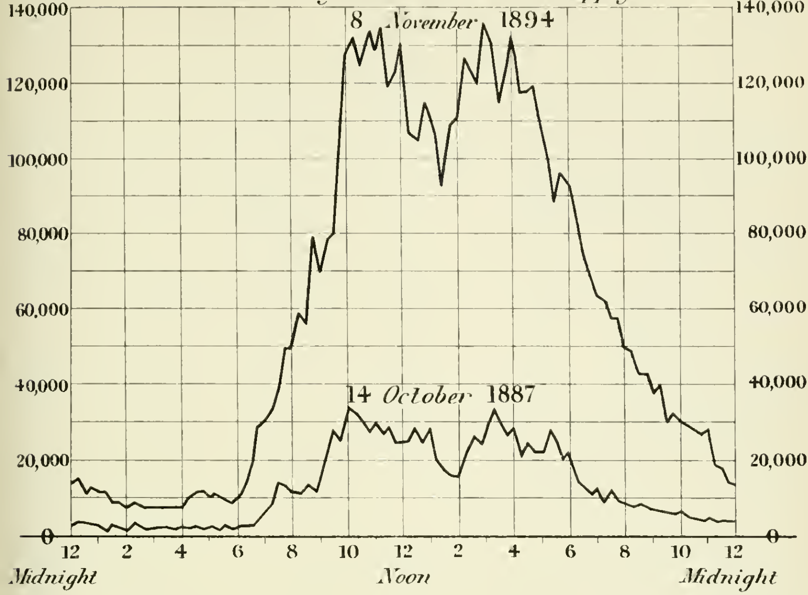
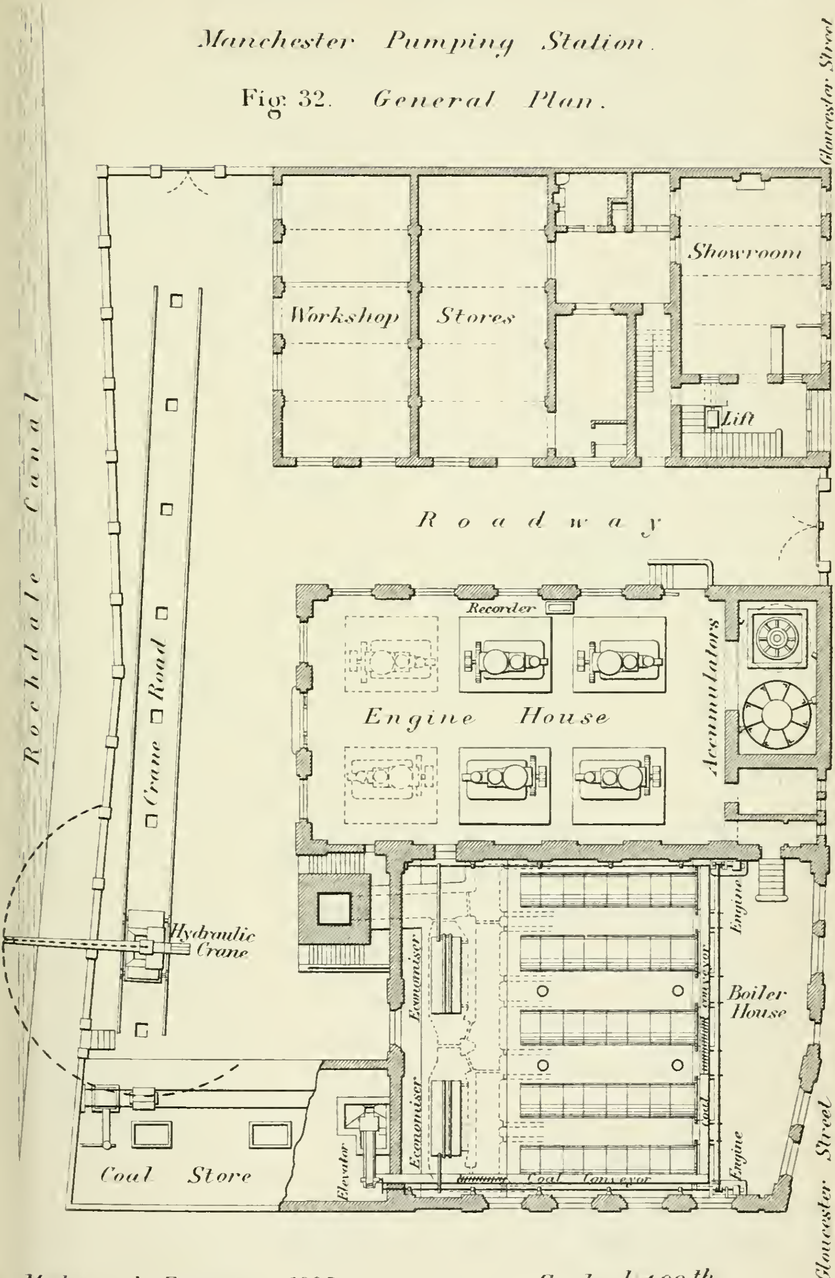


Fig. 31. *Plan of Manchester Mains.*

Scale 1,250 feet to an inch.

Manchester Pumping Station.

Fig. 32. *General Plan.*



Mechanical Engineers 1895. *Scale 1/400th*

Feet 10 5 0 10 20 30 40 50 60 70 80 90 100 110 Feet

HYDRAULIC POWER SUPPLY.

Fairbairn – Beeley Boiler.

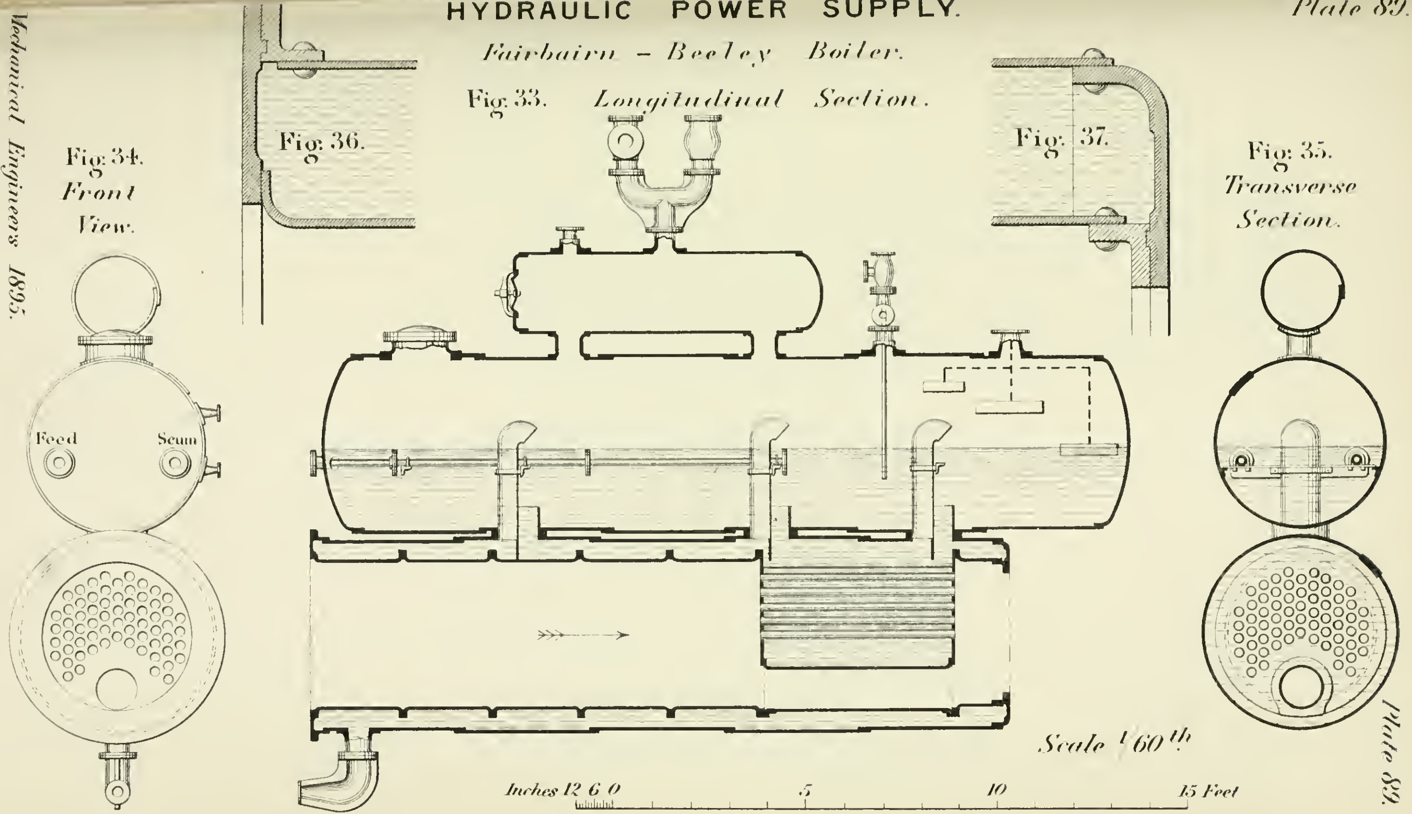
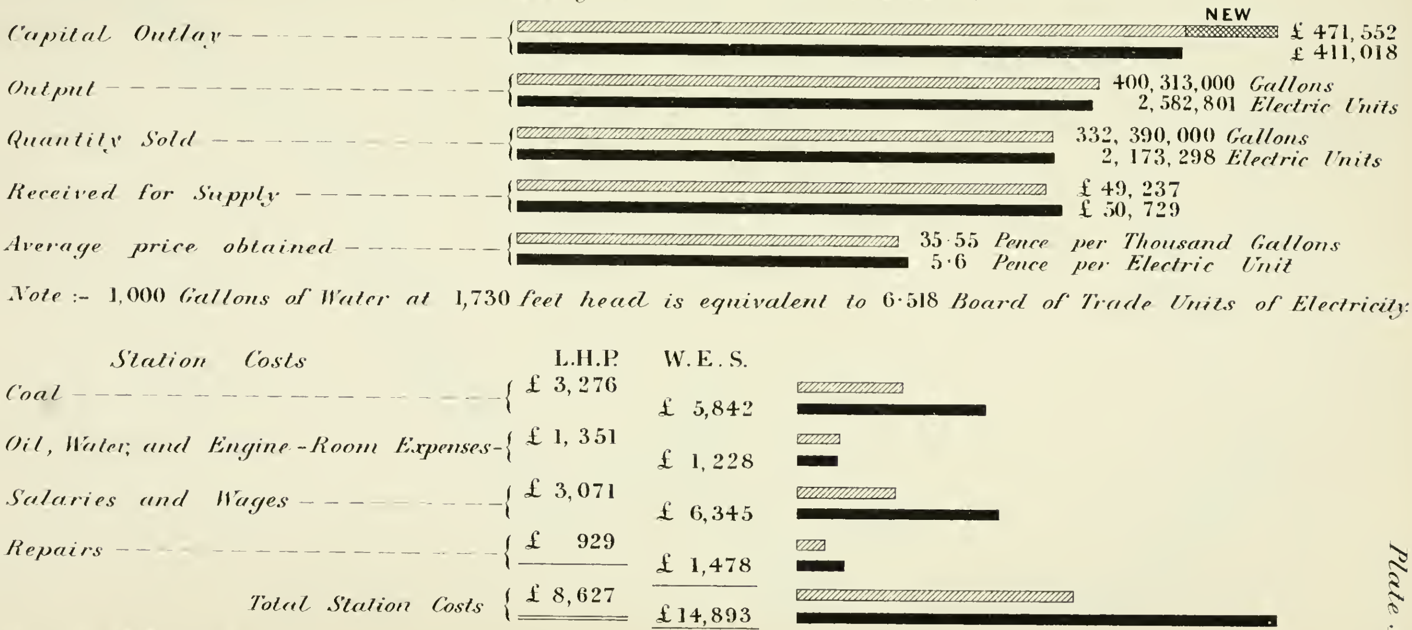


Plate 89.

HYDRAULIC POWER SUPPLY.

Fig. 38. *Comparison of Output, Station Costs, etc., of London Hydraulic Power Supply* (L.H.P.) *and Westminster Electric Supply* (W.E.S.) *for the year* 1894. *See Table* 2.



HYDRAULIC POWER SUPPLY.
Plate 91.

Buenos Aires Drainage.

Fig: 39. *Plan of Boca and Barracas districts showing Mains.*

ſechanical Engineers 1895.

Buenos Aires Drainage.

Central Hydraulic Pumping Station.

Fig. 40. *Plan.*

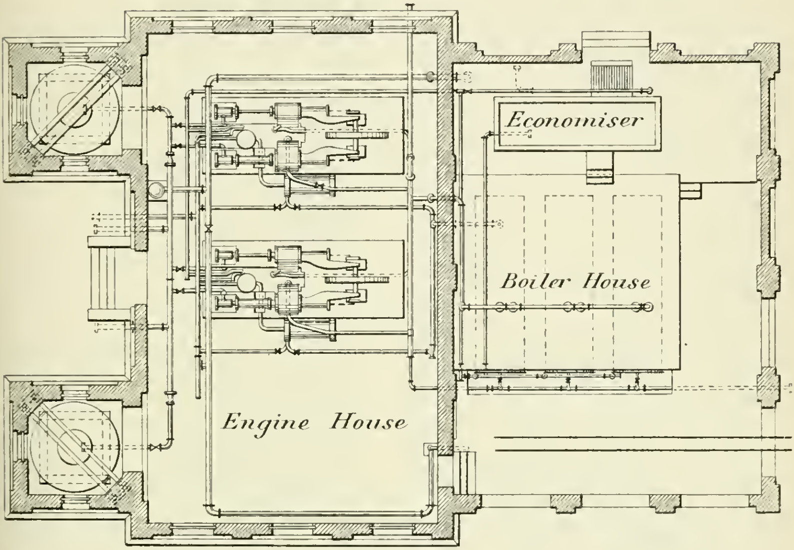
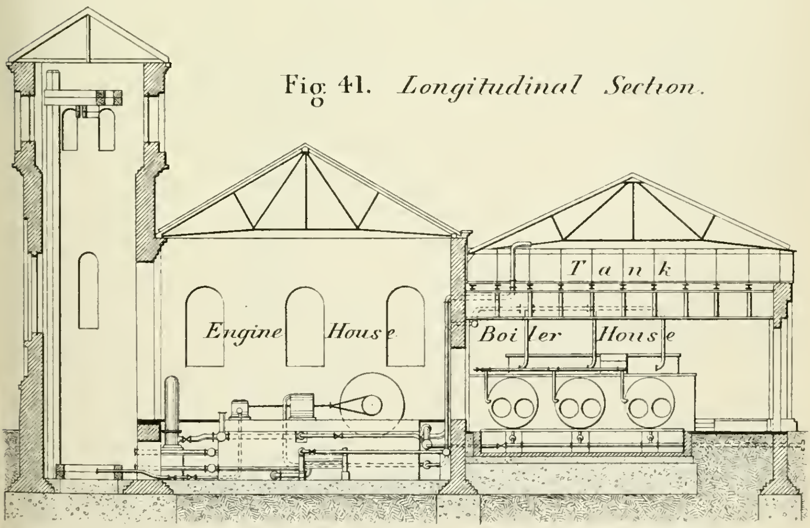


Fig. 41. *Longitudinal Section.*

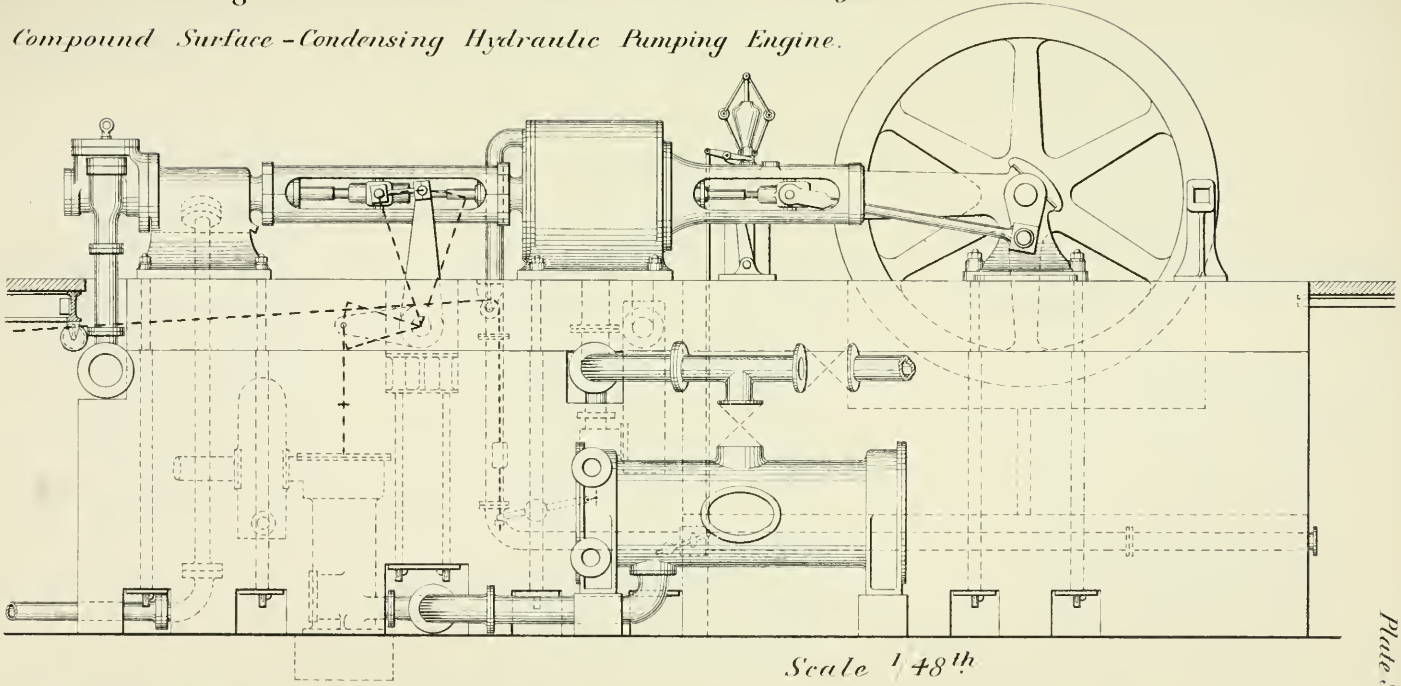


Mechanical Engineers 1895. *Scale 1/300th*

Feet 10 5 0 10 20 30 40 50 60 70 80 Feet

Fig. 42. *Buenos Aires Drainage*

Compound Surface-Condensing Hydraulic Pumping Engine.



Scale 1/48th

Inches 12 6 0 5 10 15 Feet

Plate 93.

Buenos Aires Drainage.

Hydraulic Sewage-Pumps in Sumps.

Sections of Sump.

Fig. 43. *Plan.*

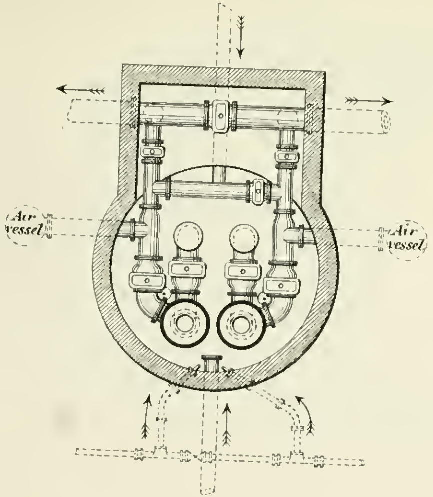


Fig. 44.

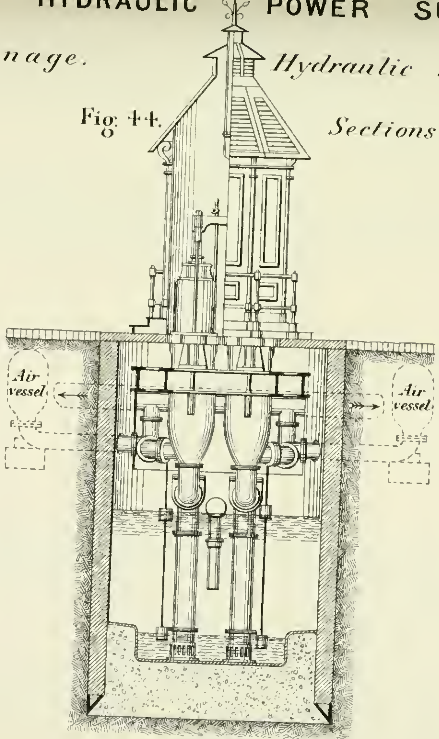
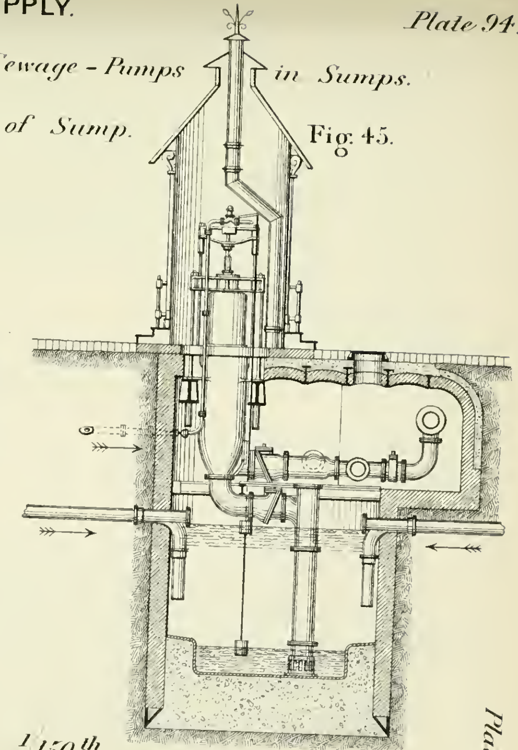


Fig. 45.



Scale 1/150th.

Feet 10 5 0 10 20 30 Feet

Plate 95.

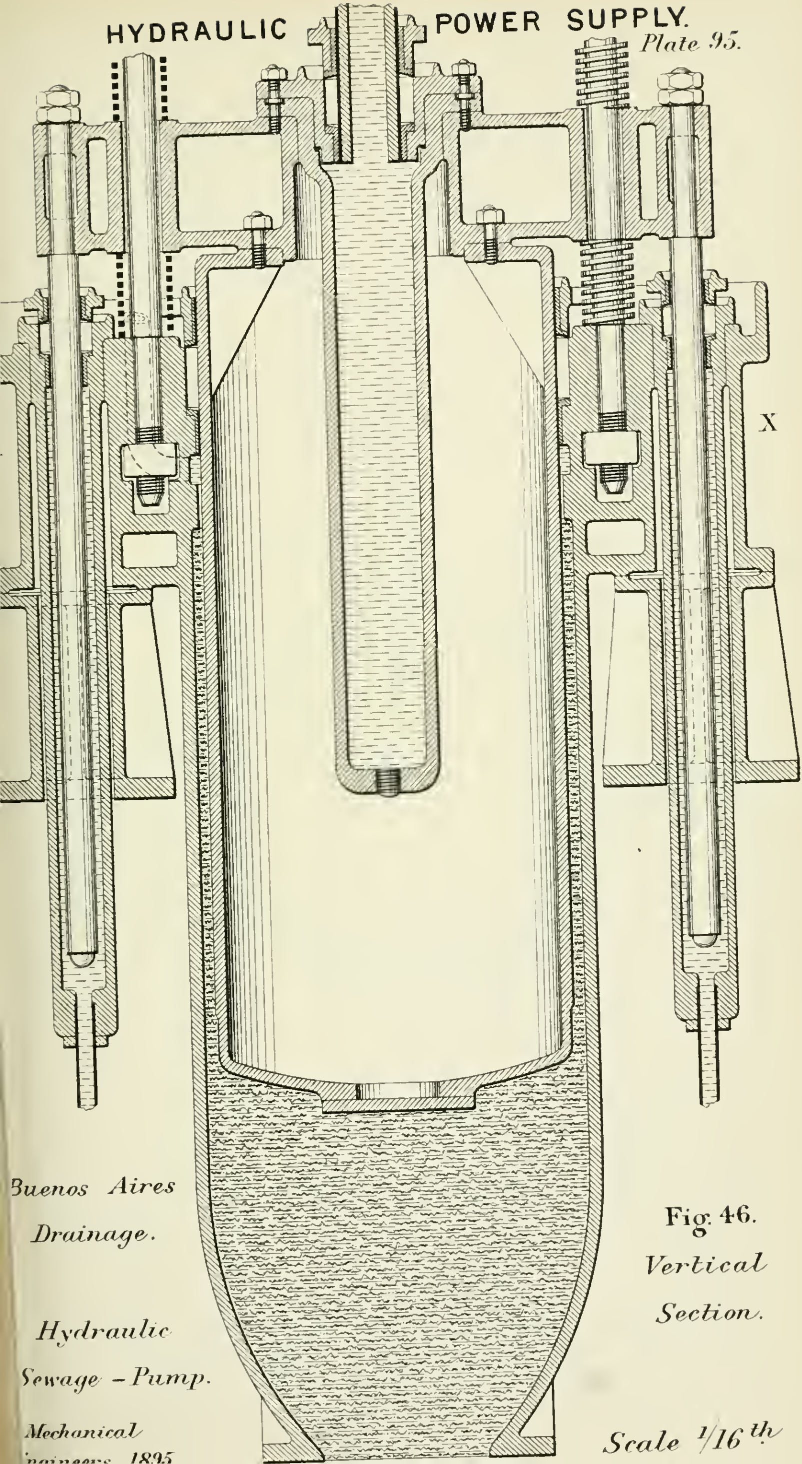
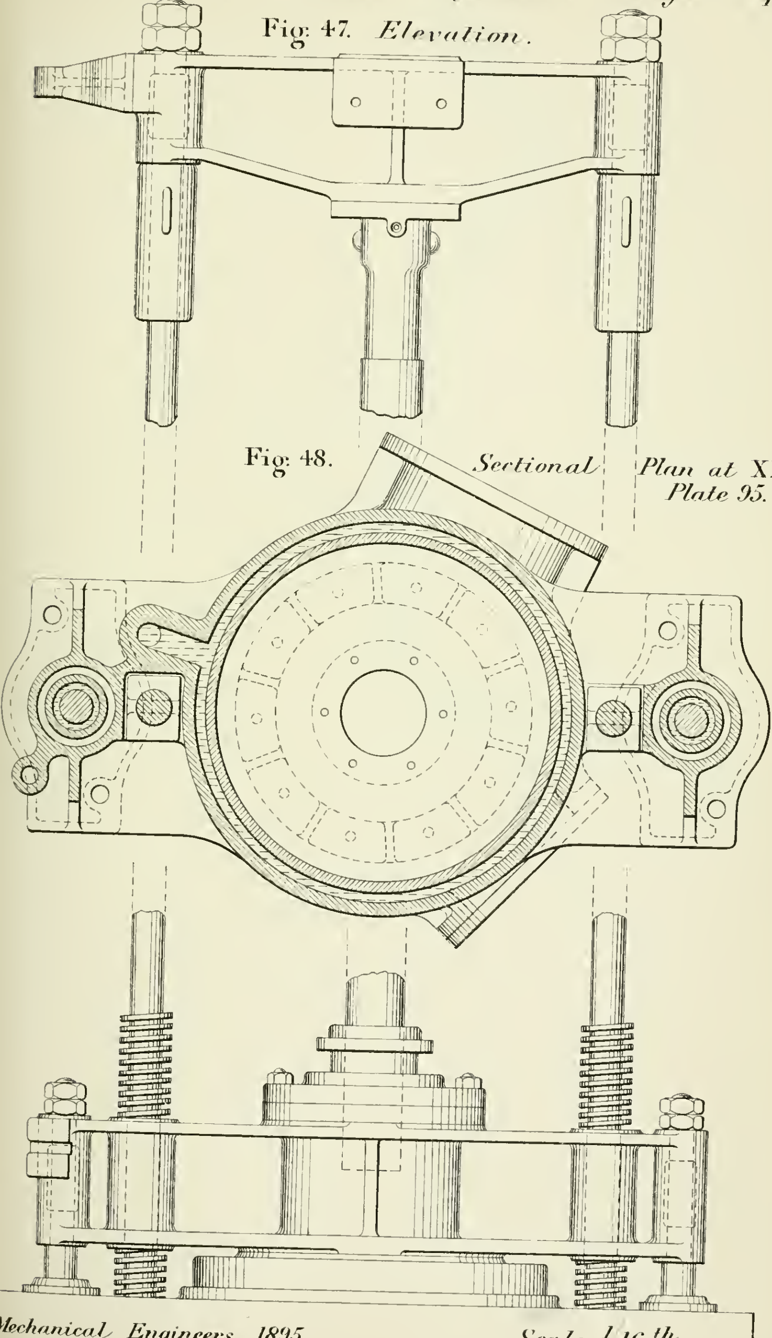


Fig. 46. Vertical Section.

Buenos Aires Drainage. Hydraulic Sewage-Pump.

Fig: 47. *Elevation.*

Fig: 48. *Sectional Plan at XX, Plate 95.*



Scale 1/16th

Inches 12 6 0 1 2 3 4 Feet

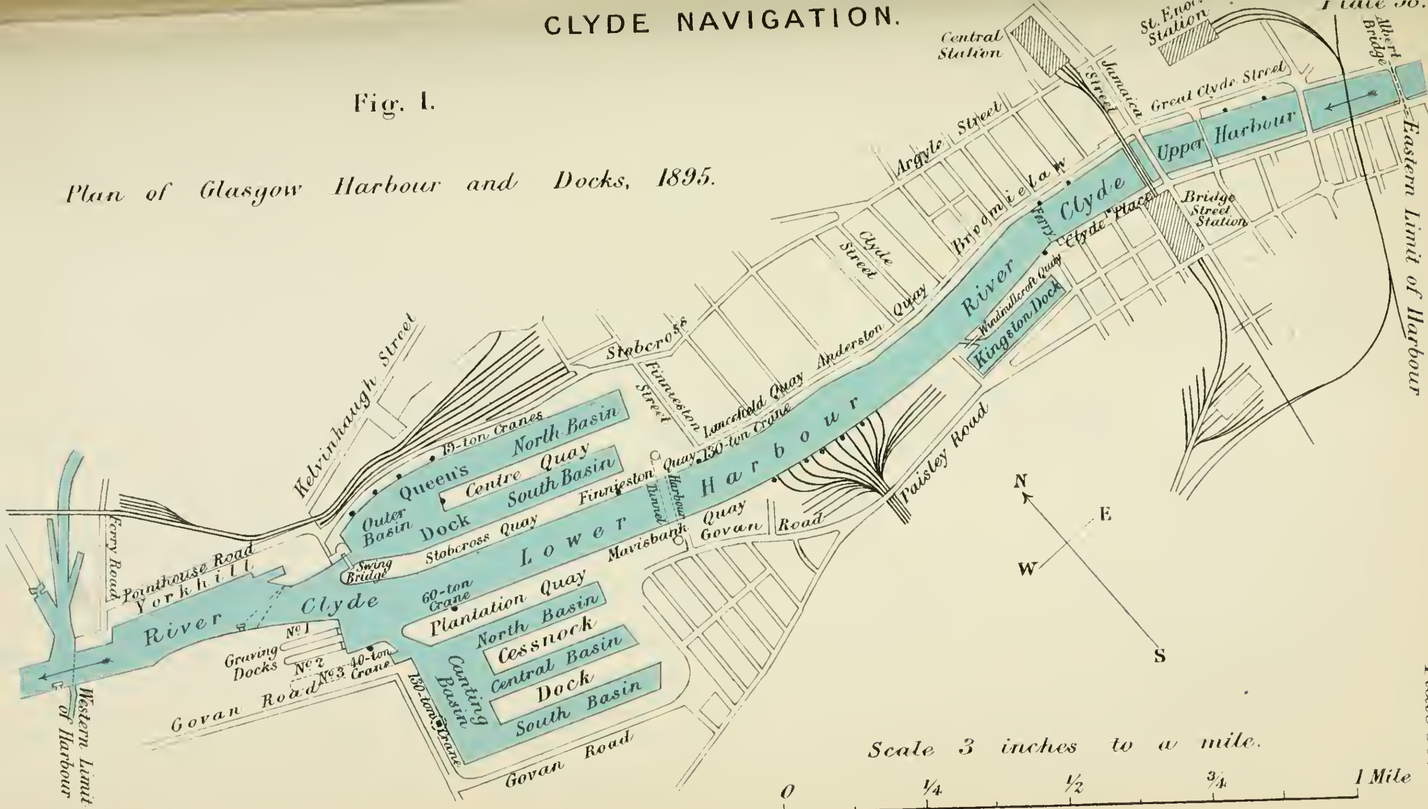
Fig: 49. *Plan of London Mains and Pumping Stations.*

Plate 97.

CLYDE NAVIGATION.

Fig. 1.

Plan of Glasgow Harbour and Docks, 1895.



Mechanical Engineers 1895.

Plate 98.

CLYDE NAVIGATION.

Fig. 2. Map of River Clyde from Carmyle to Gourock. 1895.

See continuation in Plate 100.

Mechanical Engineers 1895.

Plate 99.

CLYDE NAVIGATION.

Fig. 3. Map of River Clyde from Carmyle to Gourock.

1895.

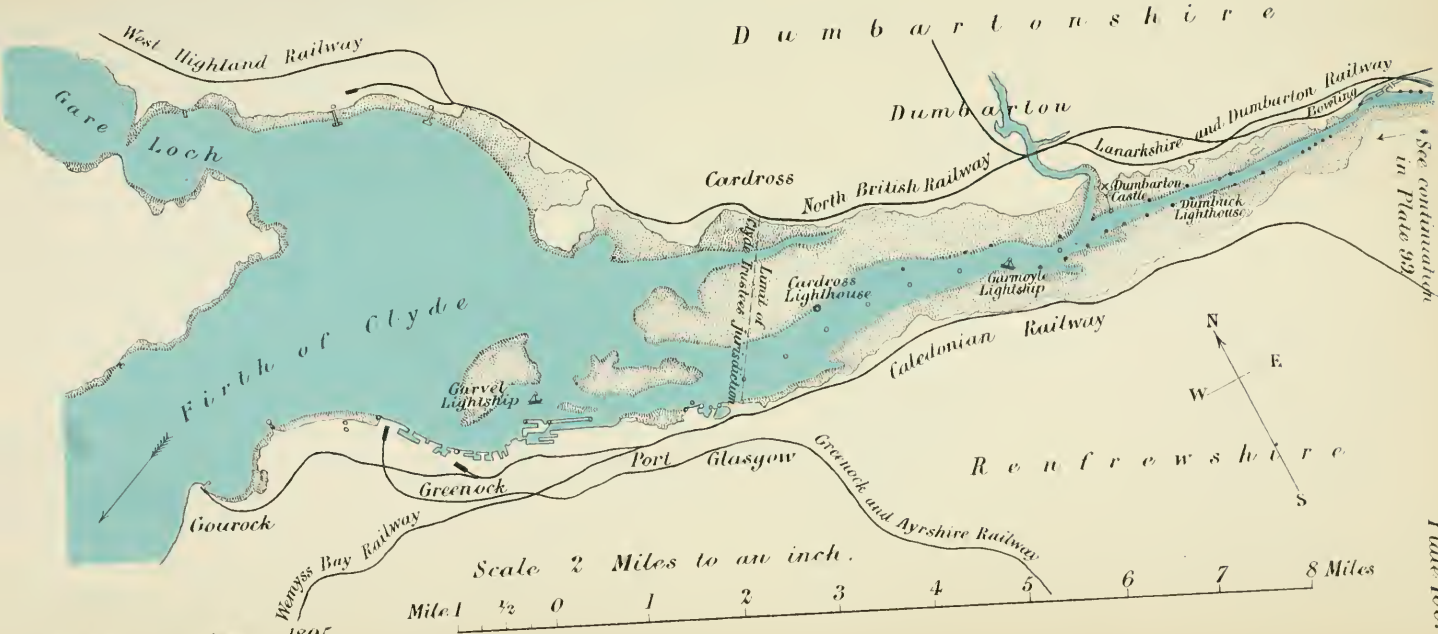
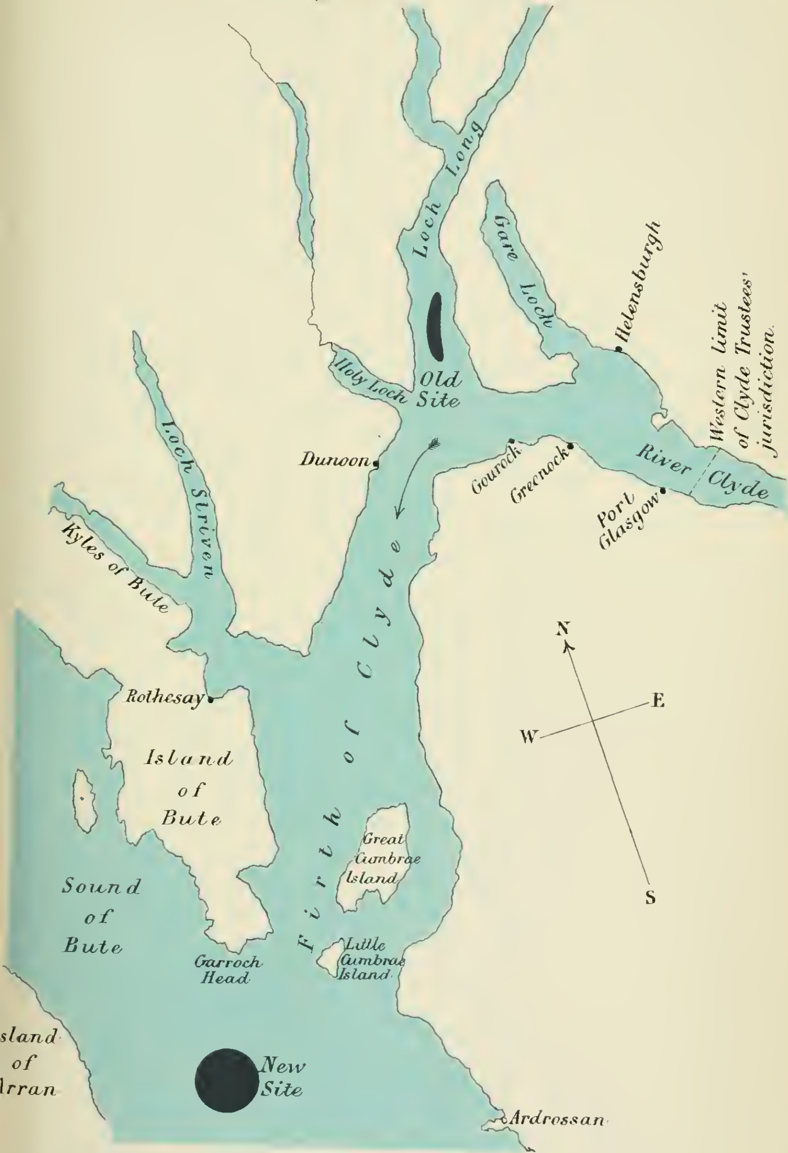


Fig. 4. *Plan of Firth of Clyde showing sites for Depositing Dredgings in Loch Long, and off Garroch Head.*

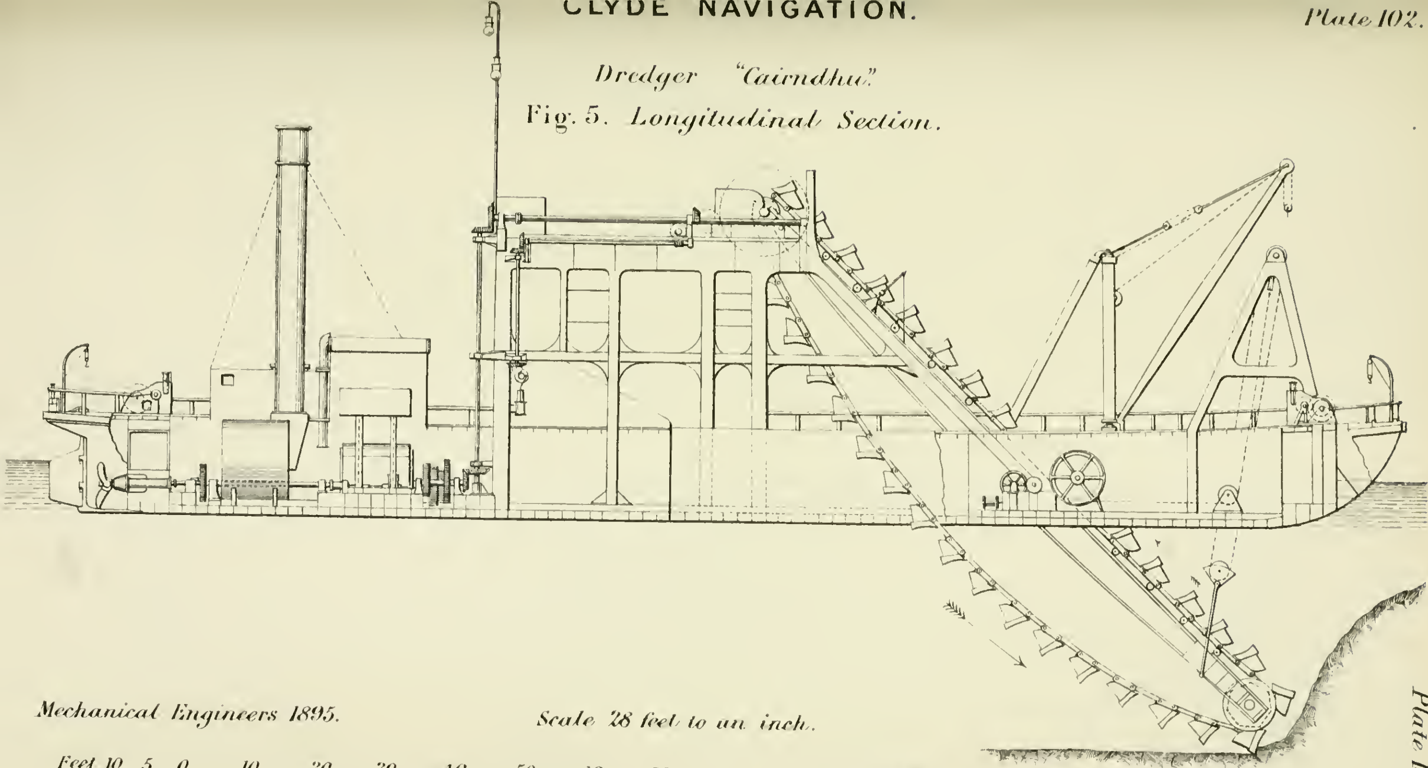


Scale 6 miles to an inch.

0 5 10 15 20 Miles

Dredger "Cairndhu."

Fig. 5. Longitudinal Section.



Mechanical Engineers 1895.

Scale 28 feet to an inch.

Feet 10 5 0 10 20 30 40 50 60 70 80 90 100 Feet

Plate 102.

Dredger "Cairndhu."

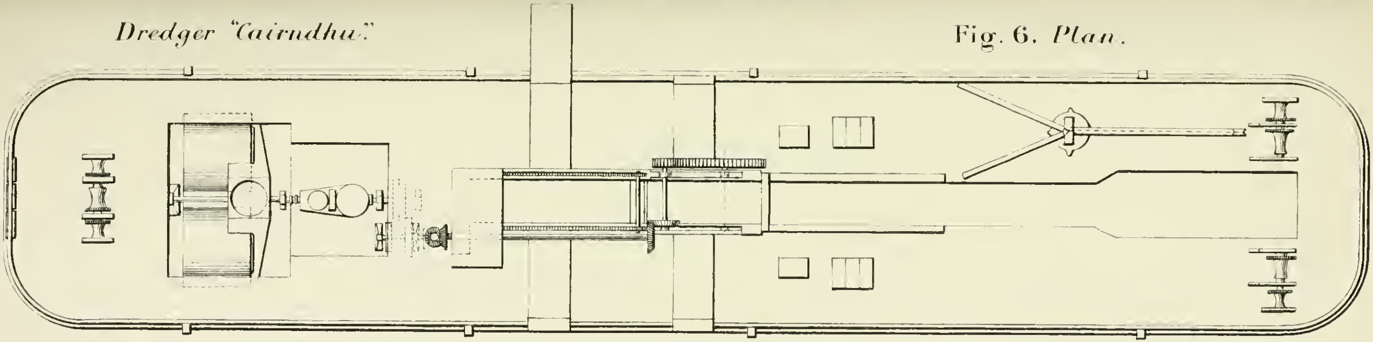


Fig. 6. Plan.

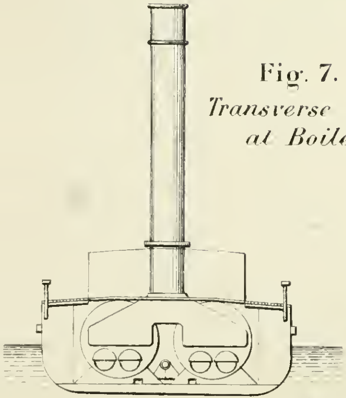


Fig. 7. Transverse Section at Boilers.

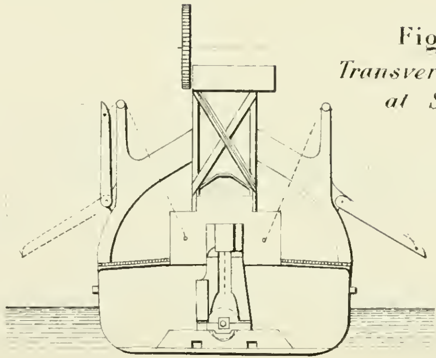


Fig. 8. Transverse Section at Shoots.

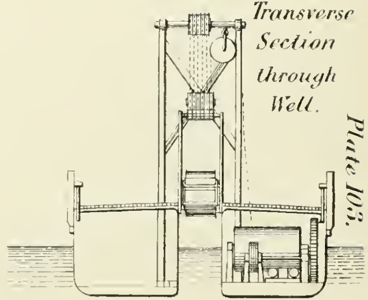


Fig. 9. Transverse Section through Well.

Scale 28 feet to an inch.

Plate 103.

Hopper Barges.
Nos 1 and 3.

Scale 28 feet to an inch.

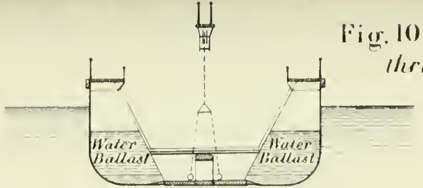


Fig. 10. *Transverse Section through hopper.*

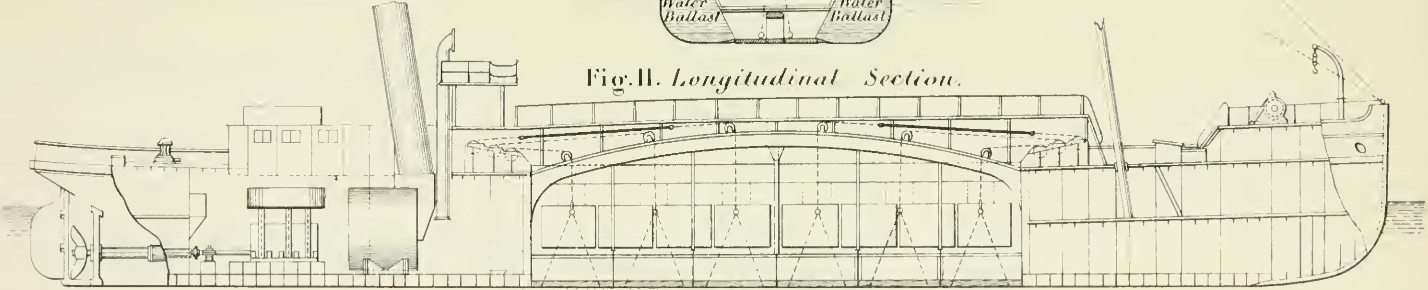
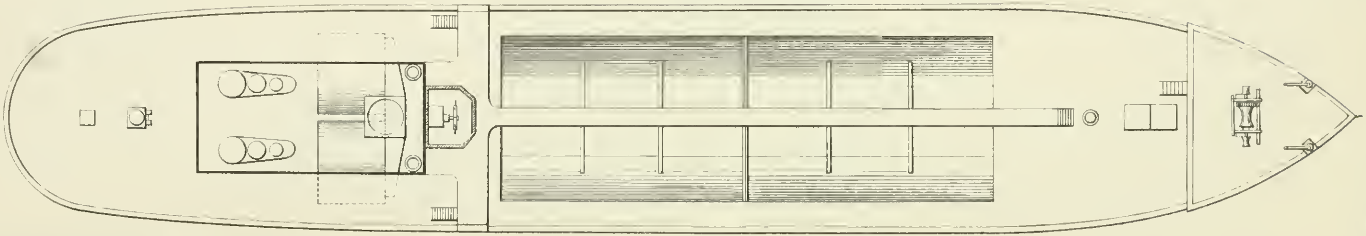
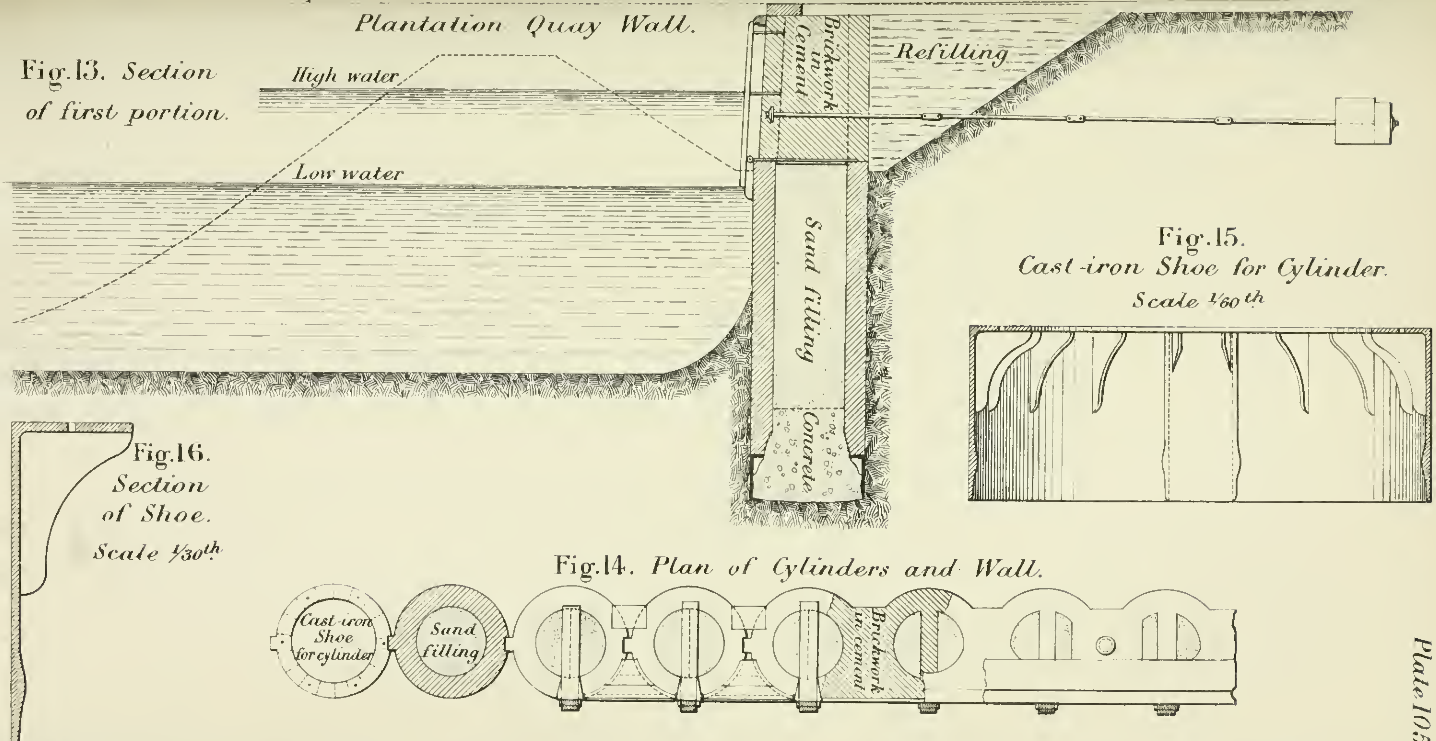


Fig. 11. *Longitudinal Section.*

Fig. 12. *Plan.*




Plantation Quay Wall.
Fig.13. Section of first portion.
Cope level
High water
Low water
Brickwork in Cement
Refilling
Sand filling
Concrete
Fig.15. Cast-iron Shoe for Cylinder. Scale 1/60th.
Fig.16. Section of Shoe. Scale 1/30th.
Fig.14. Plan of Cylinders and Wall.
Cast-iron Shoe for cylinder
Sand filling
Brickwork in cement
Scale 20 feet to an inch.
Feet 10 5 0 10 20 30 Feet

CLYDE NAVIGATION.

Plantation Quay Wall.

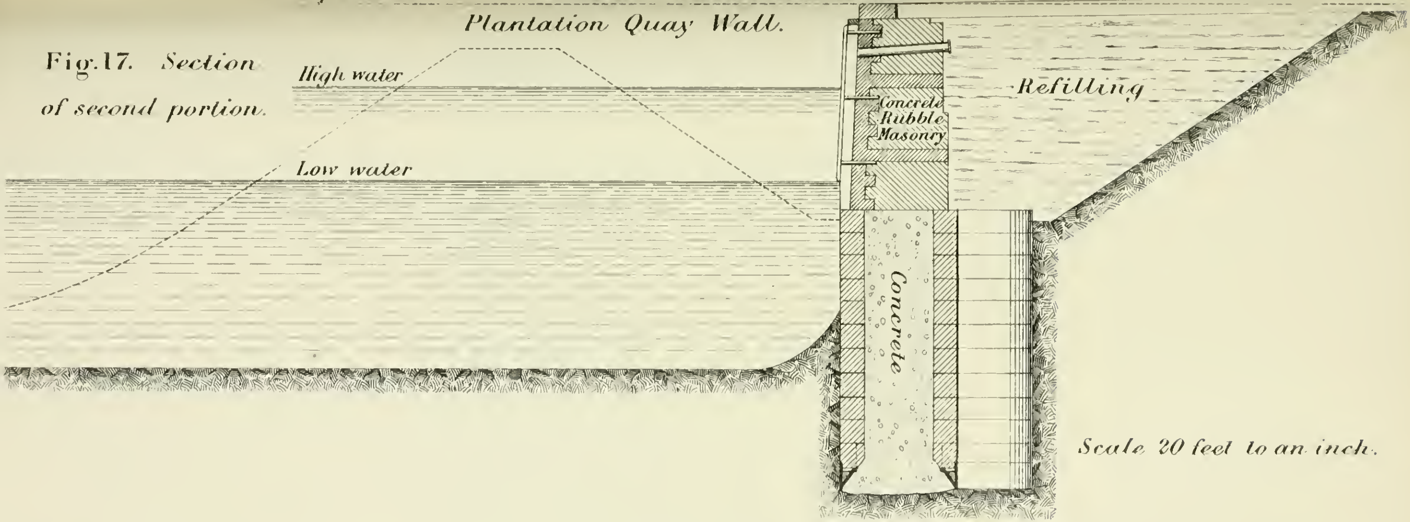


Fig. 17. Section of second portion.

Scale 20 feet to an inch.

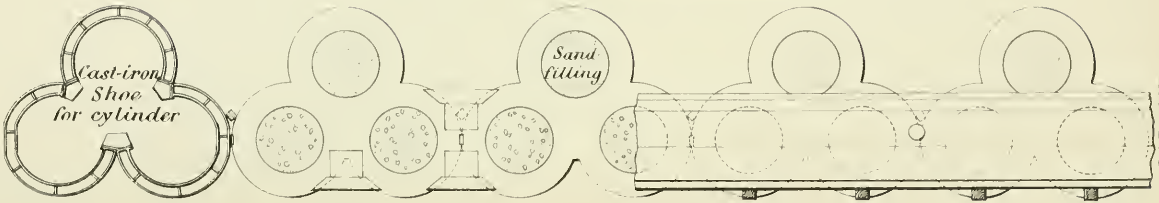


Fig. 18. Plan of Cylinders and Wall.

Plate 106.

Mechanical Engineers 1895.

CLYDE NAVIGATION.

Queen's Dock.

Fig. 19. Section of ordinary Quay Wall.

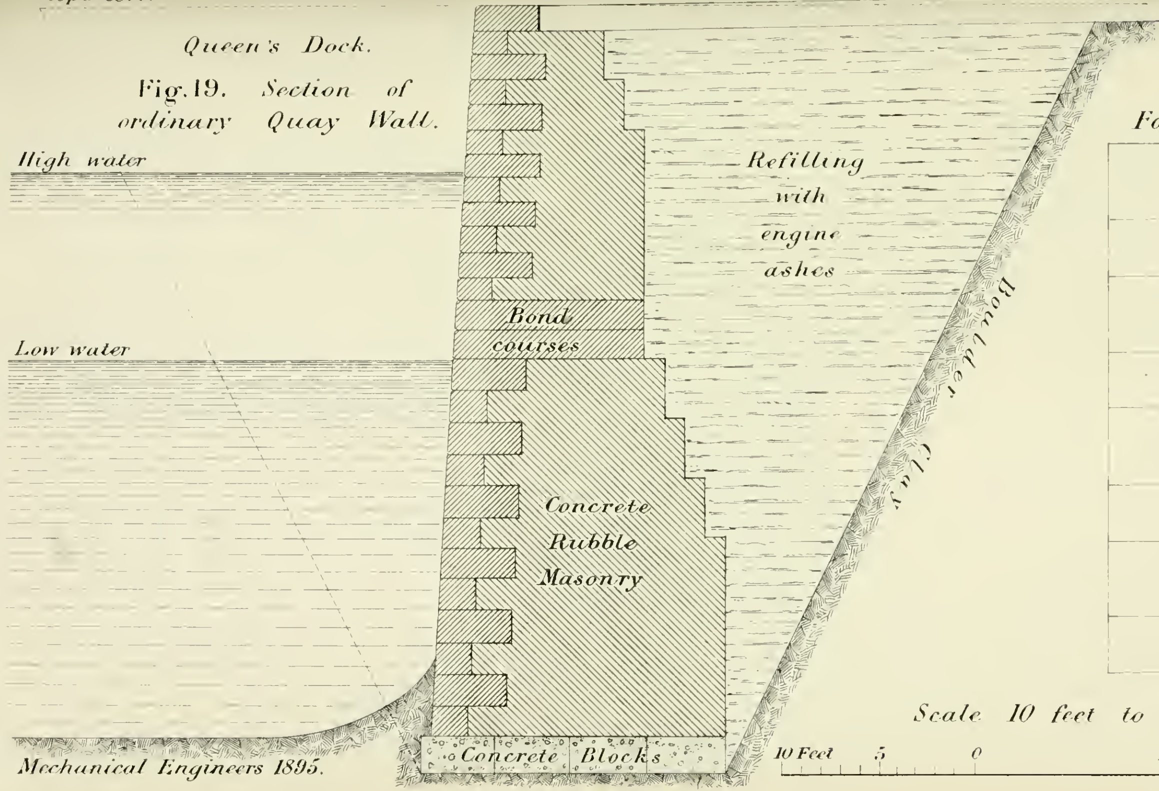


Fig. 20.

Plan of Foundation Course.

Scale 10 feet to an inch.

10 Feet 5 0 10 20 Feet

Plate 107.

Fig. 21.

Section of Quay Wall on Bearing and Sheet Piles.

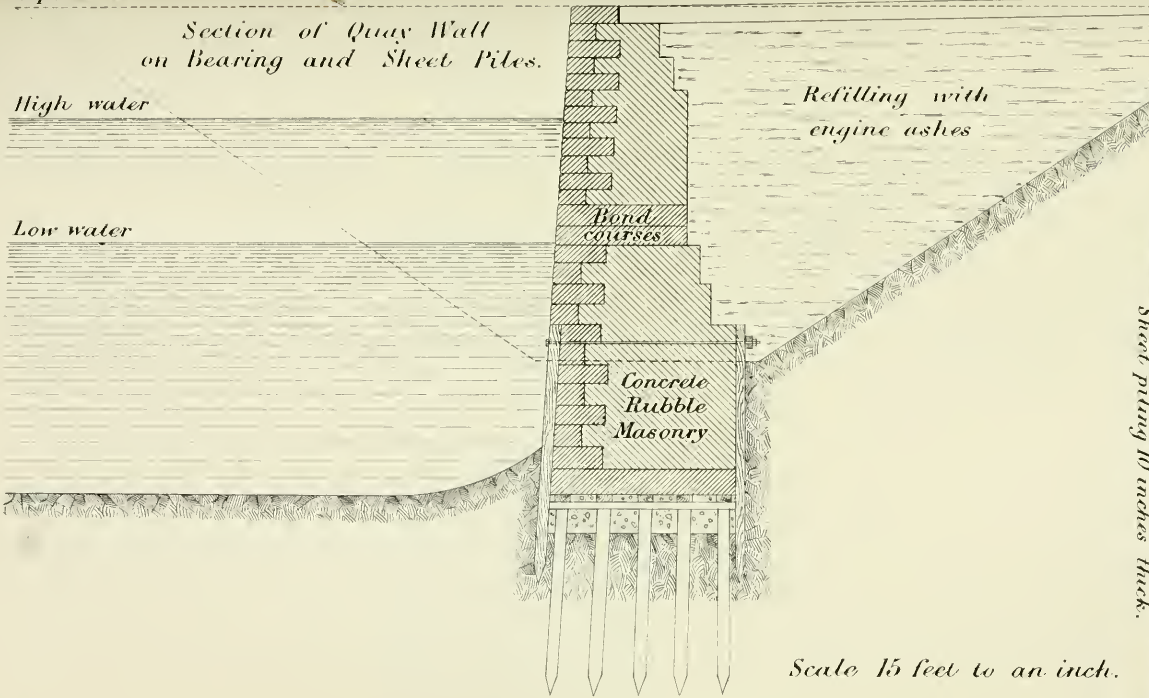
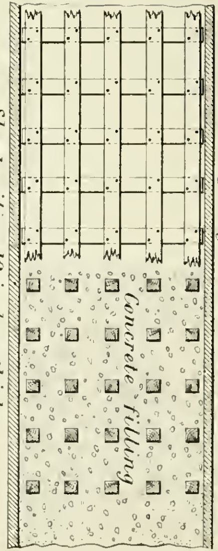


Fig. 22. Plan at top of Piles.



Scale 15 feet to an inch.

Feet 10 5 0 5 10 15 20 Feet

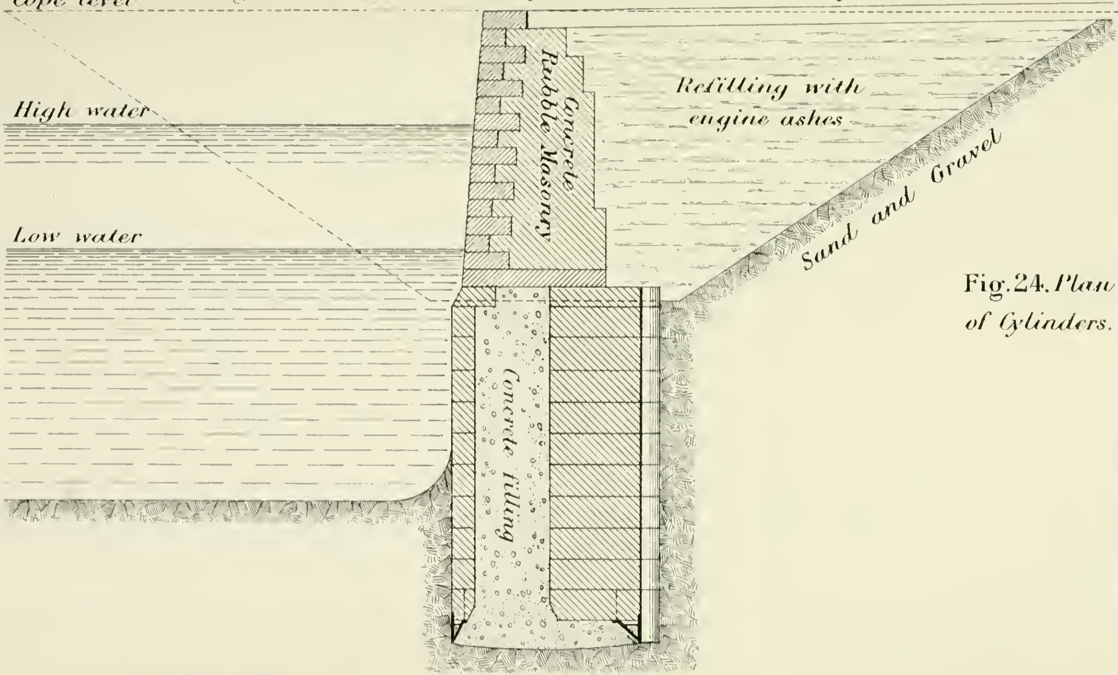
Plate 108.

Mechanical Engineers 1895.

CLYDE NAVIGATION.

Queen's Dock.

Fig. 23. Section of Quay Wall on Concrete Cylinders.



Scale 15 feet to an inch.

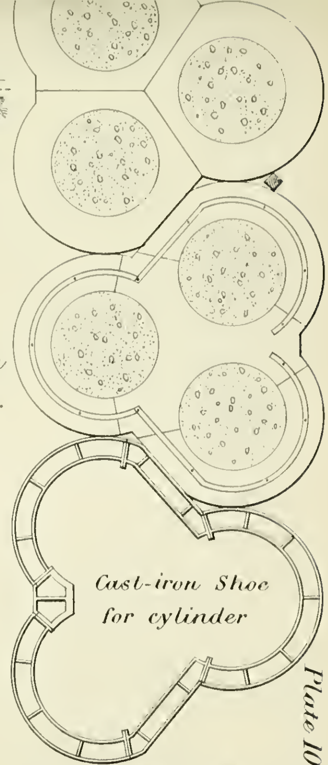


Fig. 24. Plan of Cylinders.

Scale 10 feet to an inch.

Plate 109.

CLYDE NAVIGATION.

Queen's Dock. *Cast-iron Shoe for Cylinder.*

Fig. 29. *Section at Joint J. Scale 1/8th.*

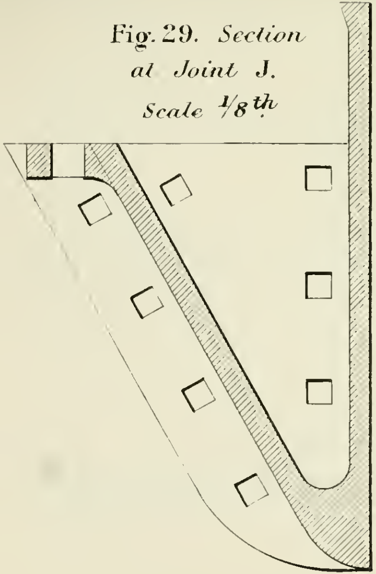
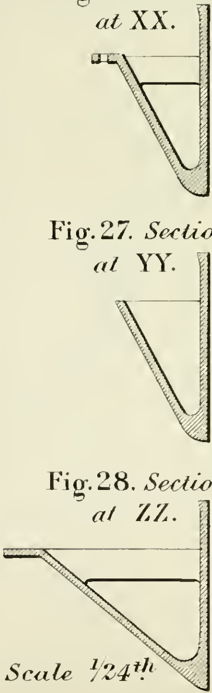


Fig. 26. *Section at XX.*

Fig. 27. *Section at YY.*

Fig. 28. *Section at ZZ.*



Scale 1/24th.

Fig. 25. *Plan of Shoe.*

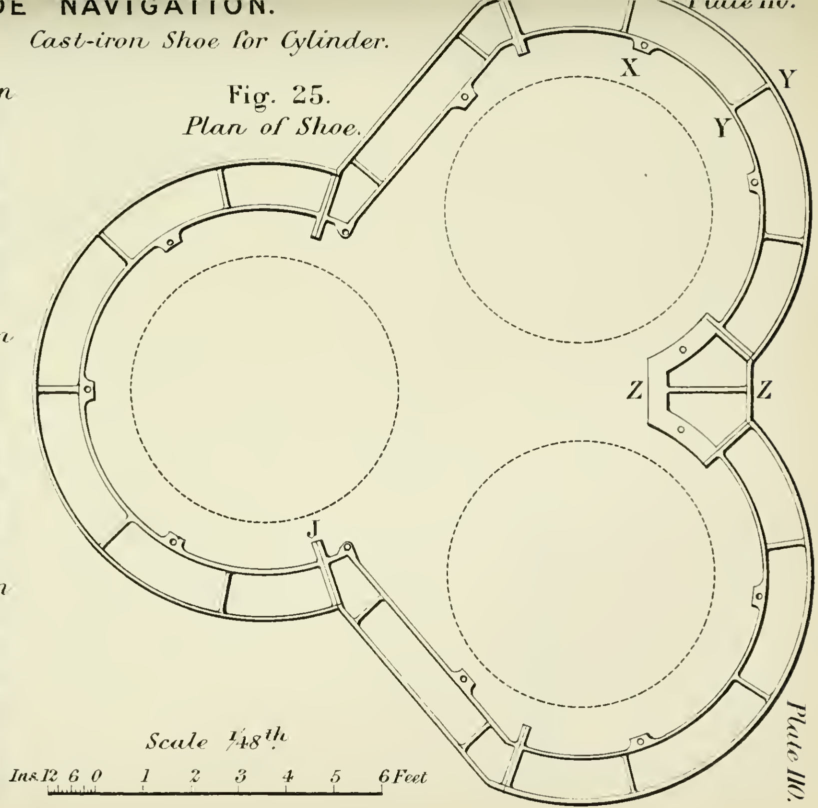


Plate 110.

CLYDE NAVIGATION.

Queen's Dock.

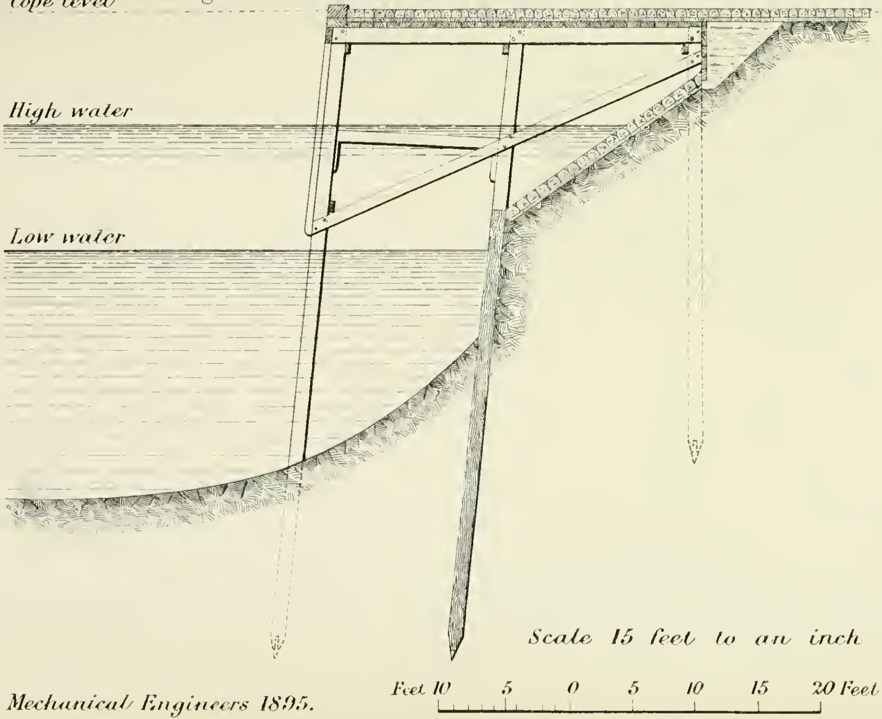


Fig. 30. Section of Wharf.

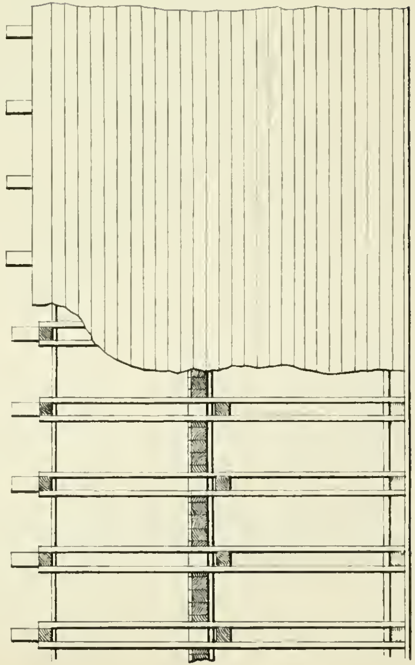
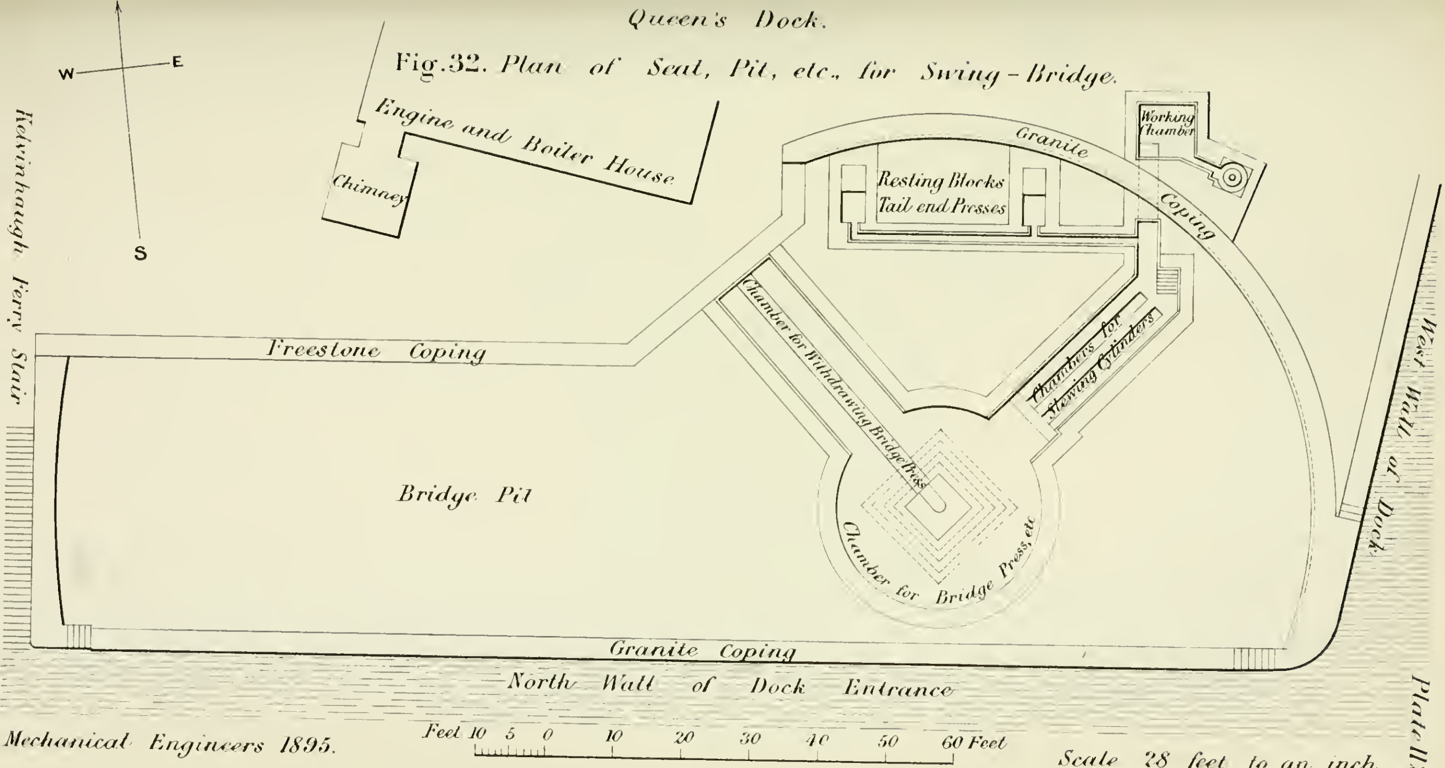


Fig. 31. Plan.

Plate III.

Plate 112.

Fig. 32. Plan of Seat, Pit, etc., for Swing-Bridge.

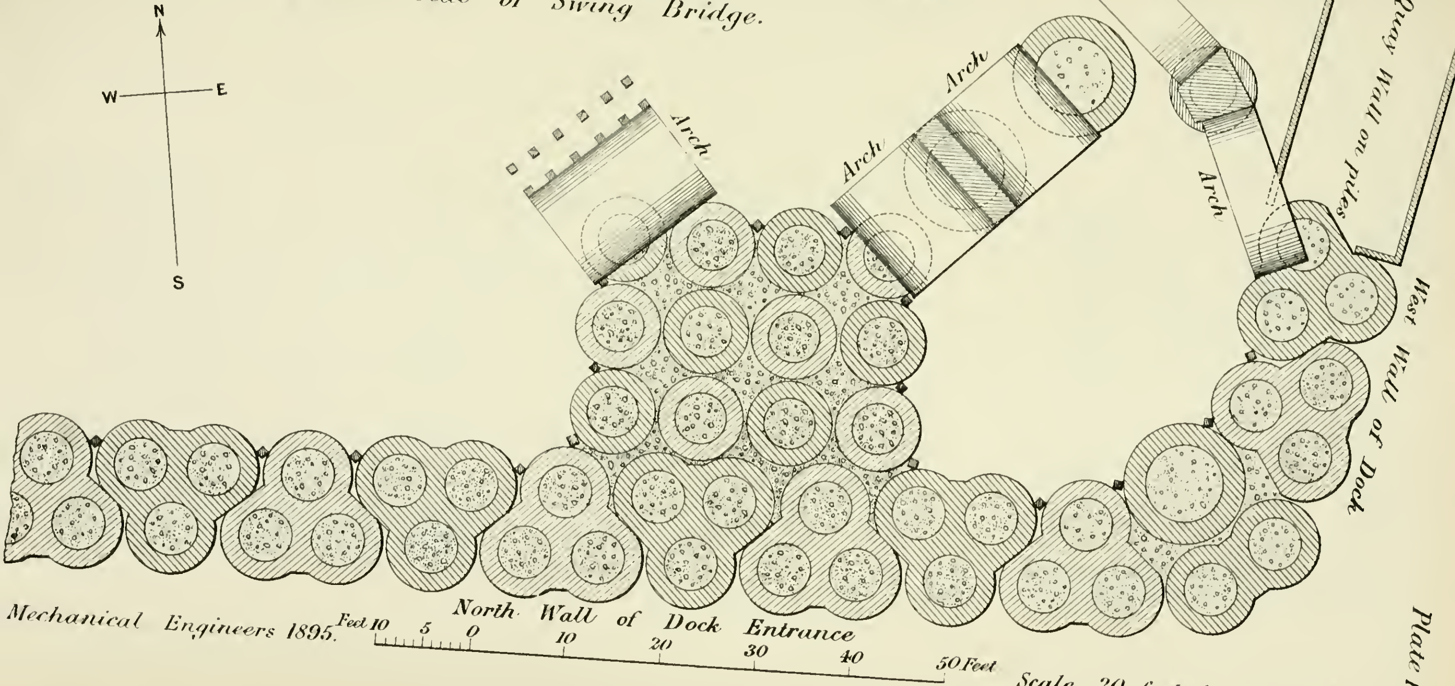


Scale 28 feet to an inch.

Mechanical Engineers 1895.

Queen's Dock.

Fig. 33. Plan of Cylinders for North Wall of Dock Entrance, and for Seat of Swing Bridge.



Scale 20 feet to an inch.

CLYDE NAVIGATION.

Queen's Dock.

Seat for Swing Bridge.

Fig. 34. Section south and north.

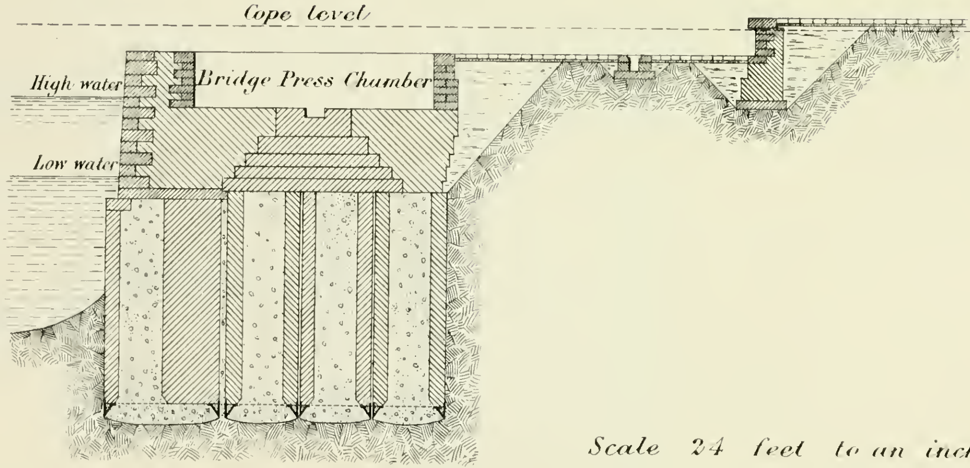
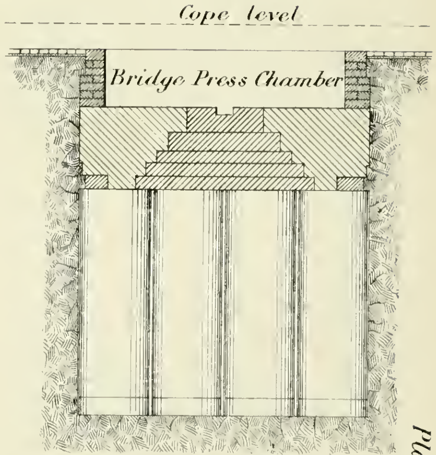


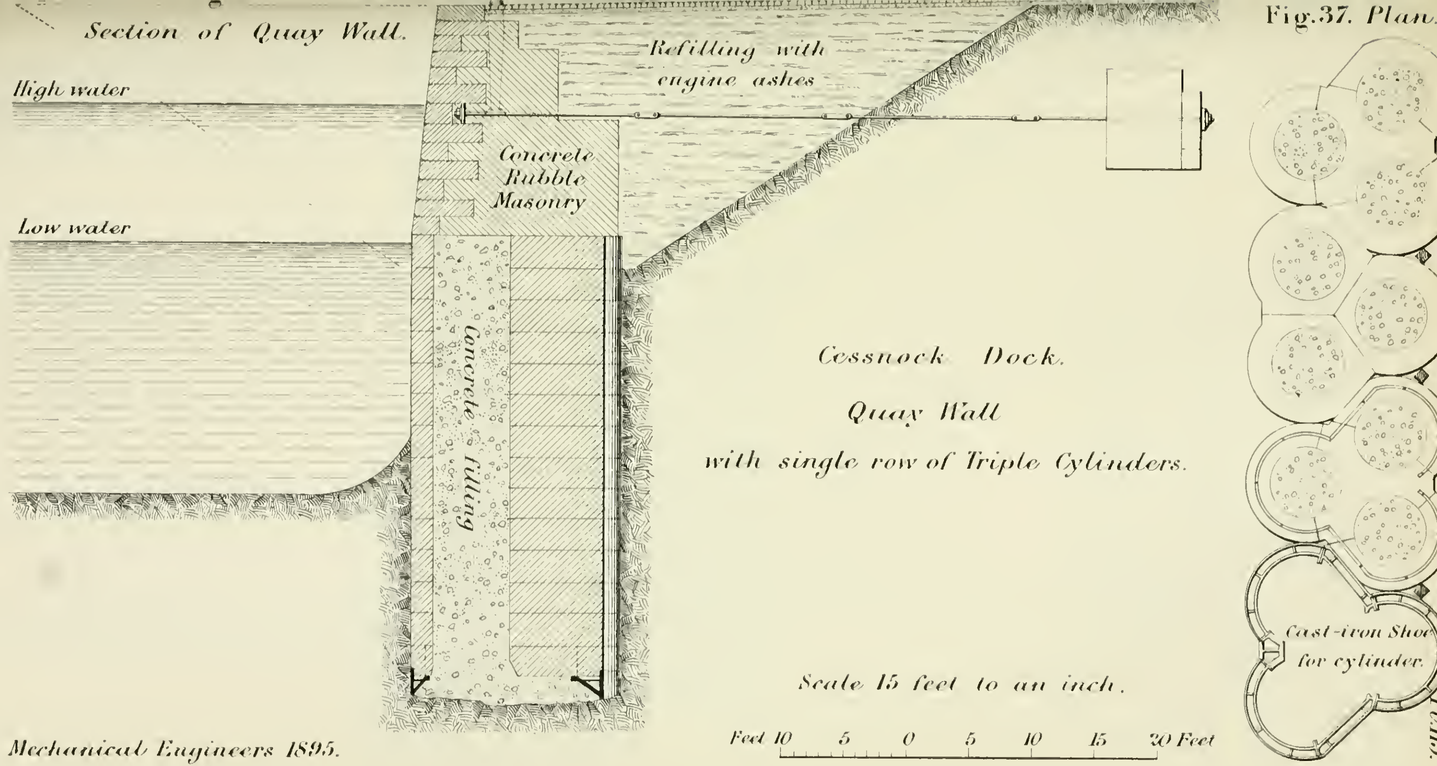
Fig. 35. Section west and east.



Scale 24 feet to an inch.

Plate 114.

Fig.37. Plan.



Cessnock Dock.

Quay Wall

with single row of Triple Cylinders.

Scale 15 feet to an inch.

Mechanical Engineers 1895.

Fig. 38. Section of Quay Wall.

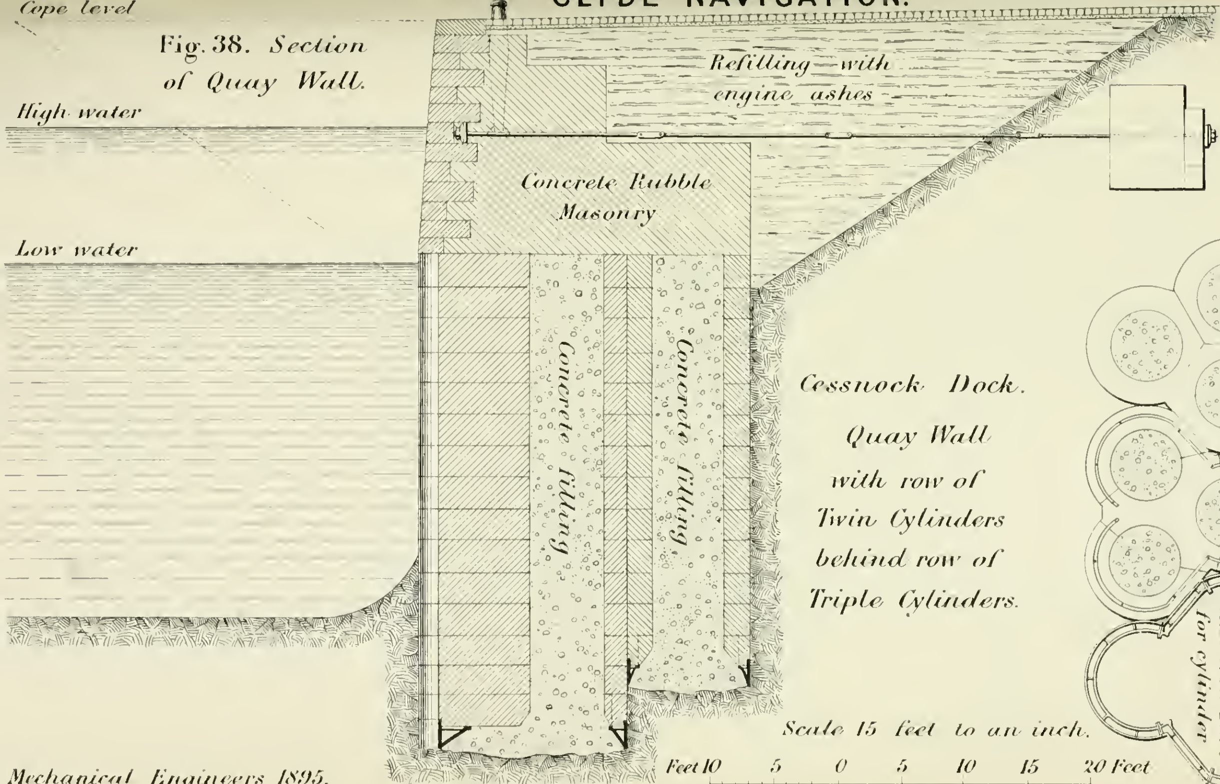
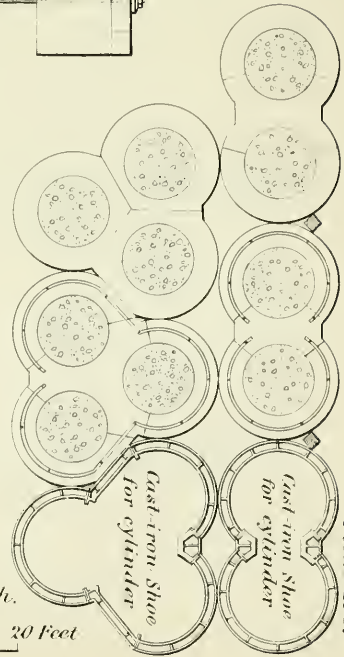


Fig. 39. Plan.



Cessnock Dock.

Quay Wall with row of Twin Cylinders behind row of Triple Cylinders.

Scale 15 feet to an inch.

Feet 10 5 0 5 10 15 20 Feet

Cessnock Dock. *Seat for 130-ton Crane.*

Fig. 40.

Vertical Section.

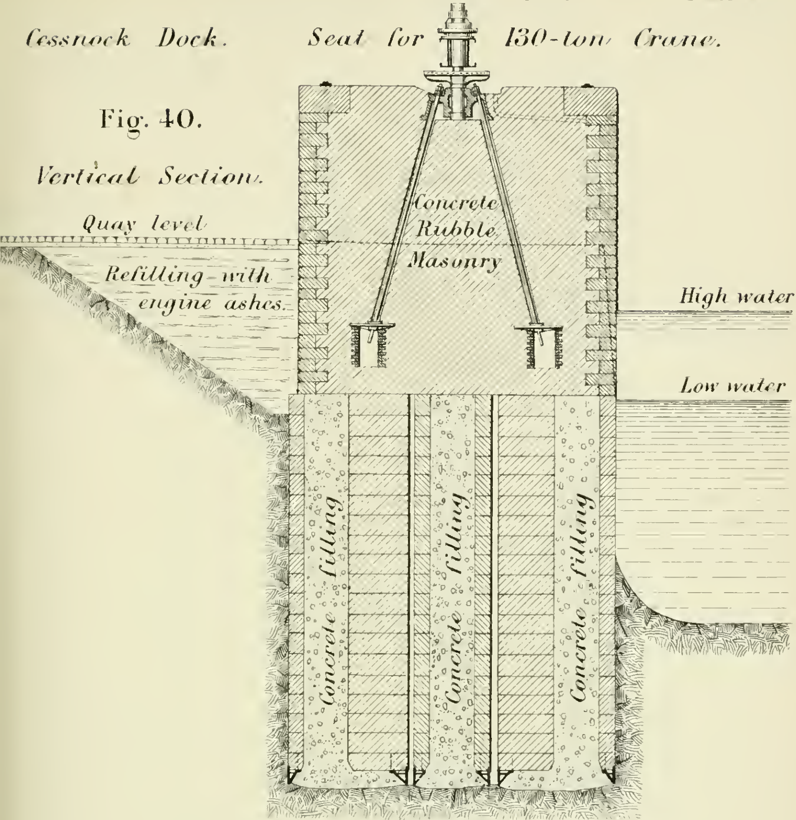
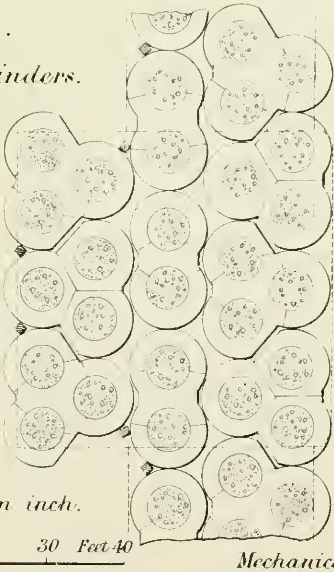


Fig. 41.

Plan of Cylinders.



Scale 24 feet to an inch.

Feet 10 5 0 10 20 30 Feet 40

CLYDE NAVIGATION. *Plate 118.*

Cessnock Dock. Seat for 130-ton Crane.

Fig. 42. *Plan at top.*

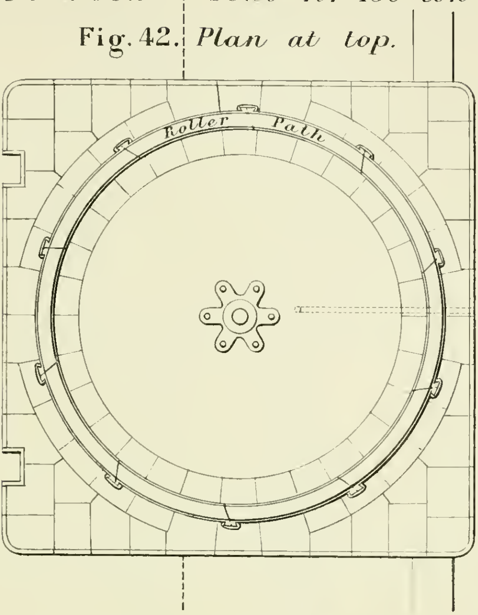
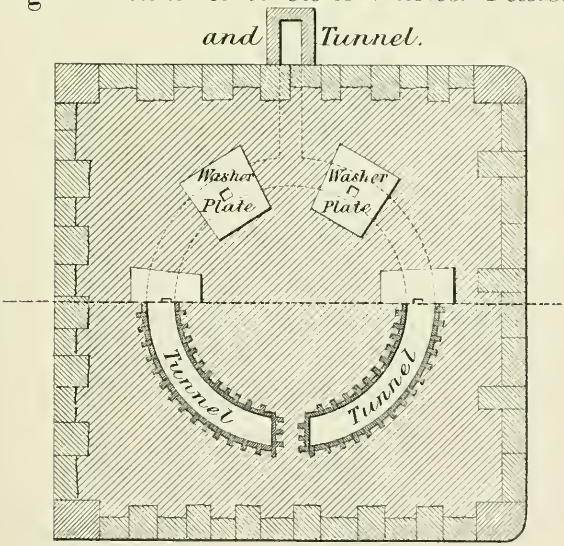


Fig. 43. *Plans at levels of Washer-Plates and Tunnel.*



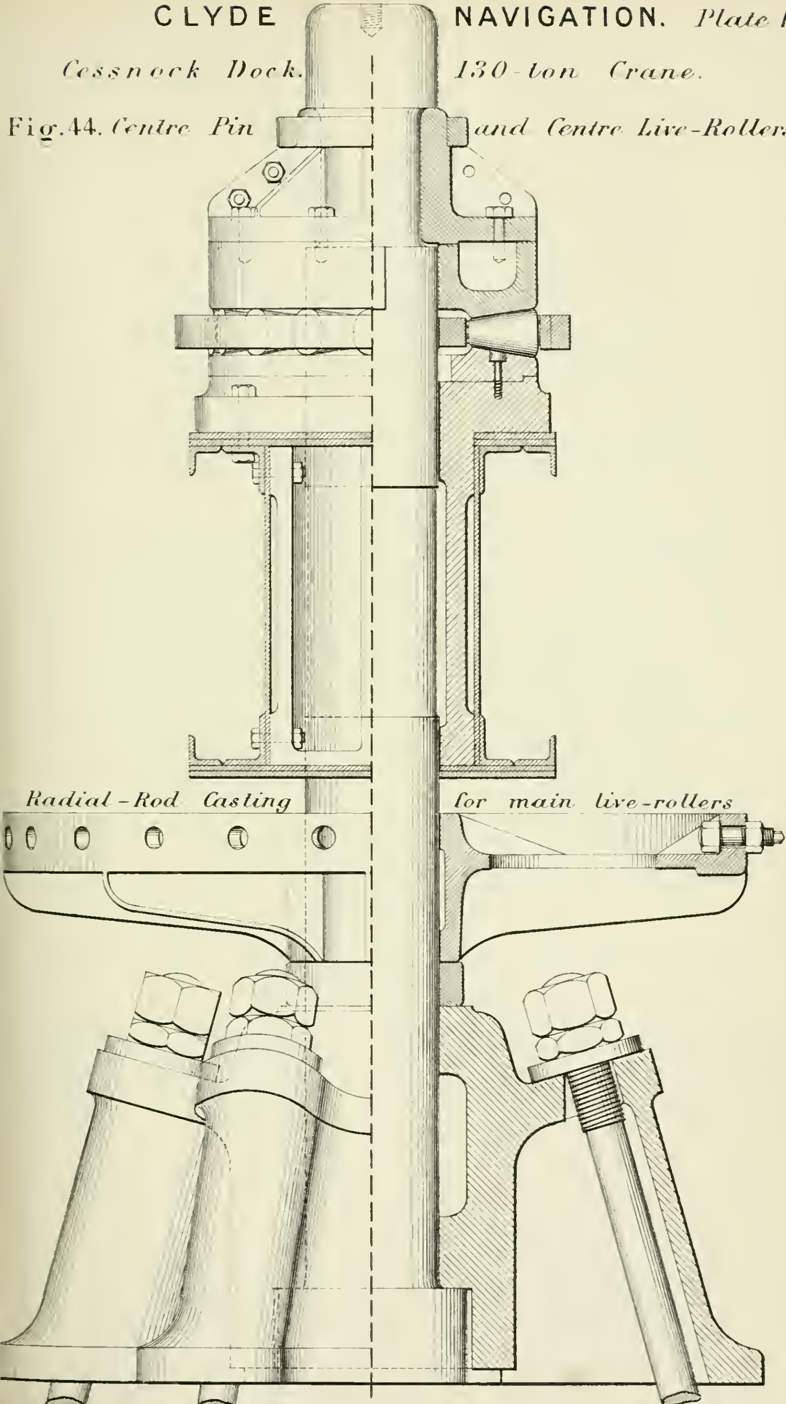
Mechanical Engineers 1895. *Scale 16 feet to an inch.*

Feet 10 5 0 10 20 30 Feet

CLYDE NAVIGATION. *Plate 119.*

Cessnock Dock. 130-ton Crane.

Fig. 44. *Centre Pin and Centre Live-Rollers.*



 Scale 1/24th Ins 12 6 0 1 Feet 2

CLYDE NAVIGATION. *Plate 120.*

Cessnock Dock. 130-ton Crane.

Fig. 45. *Plan of Centre Live-Rollers and Ring.*

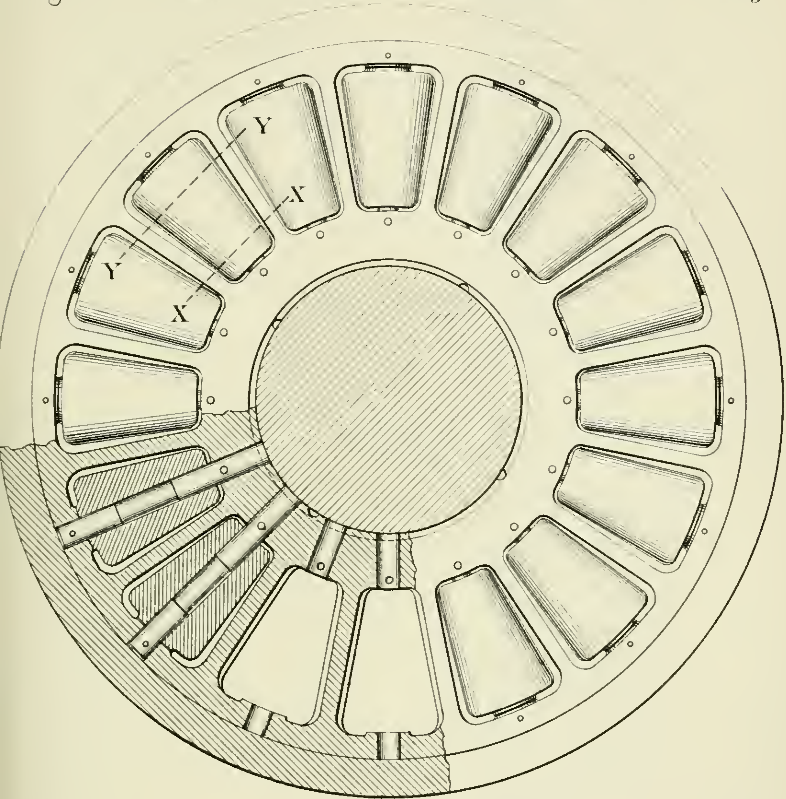


Fig. 46. *Elevation and Section.*

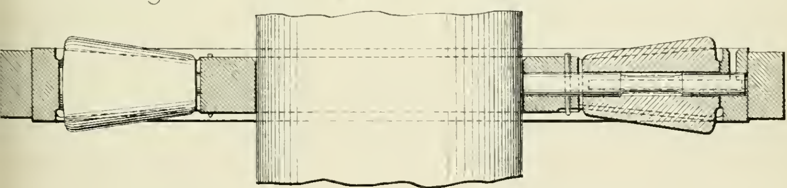


Fig. 47.

Section at X X.

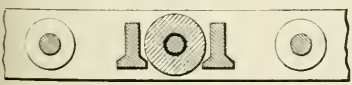
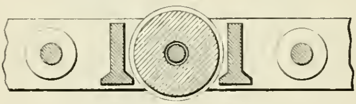


Fig. 48.

Section at Y Y.

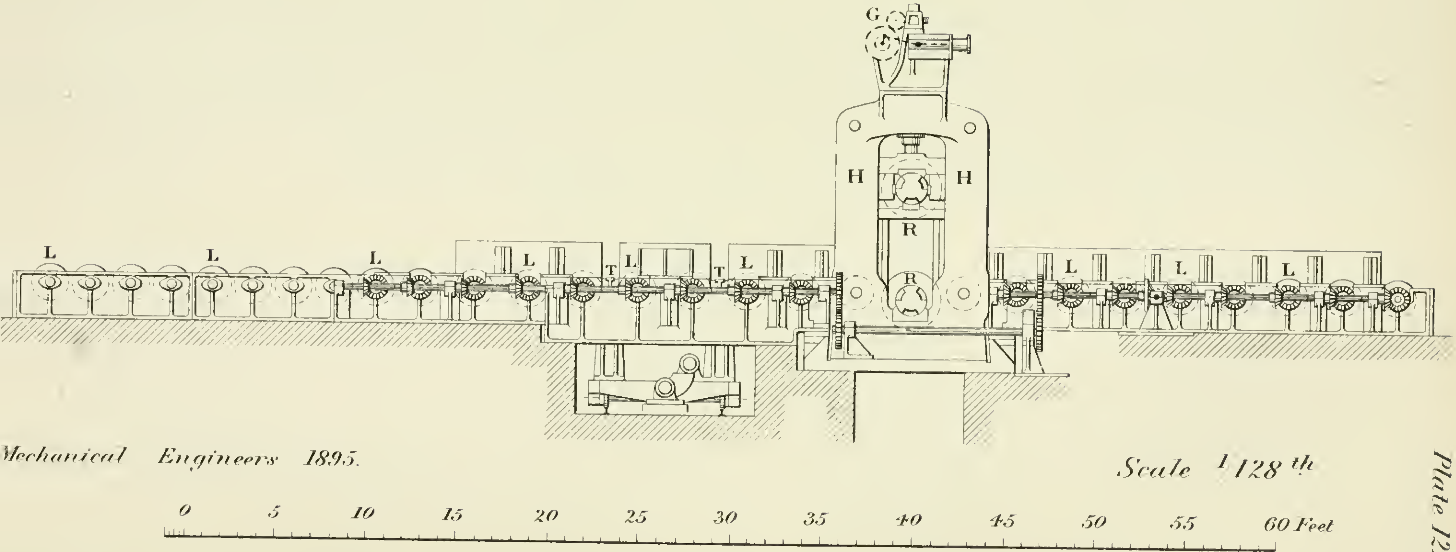


Mechanical Engineers 1895. *Scale 1/12 th.*

Inches 12 6 0 1 2 *Feet*

40-*inch Slab-Cogging Mill.*

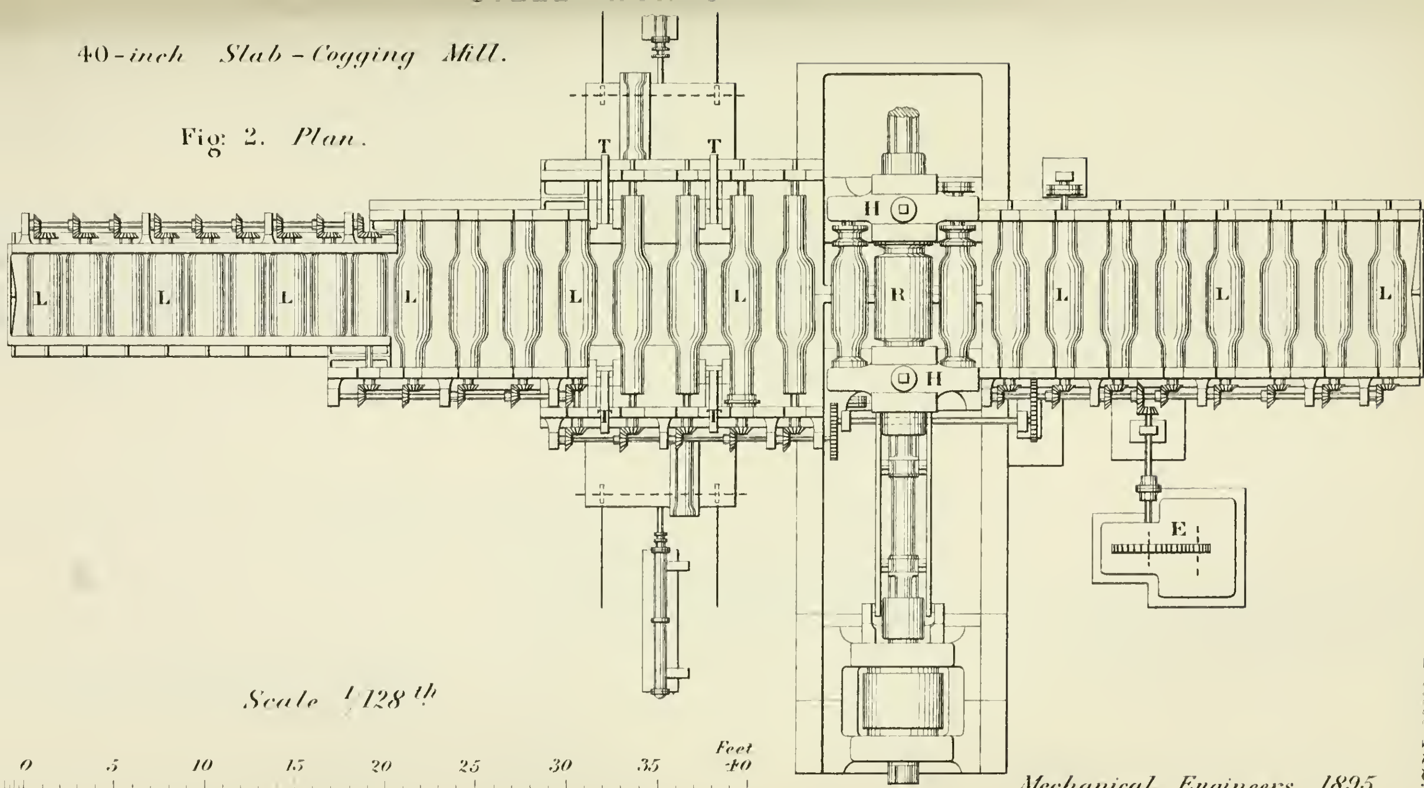
Fig: 1. *Side Elevation.*



Scale 1/128th

40-inch Slab-Cogging Mill.

Fig: 2. *Plan.*



Scale 1/128th

Mechanical Engineers 1895.

Plate 122.

Tilting Gear for 40-inch Slab-Cogging Mill.

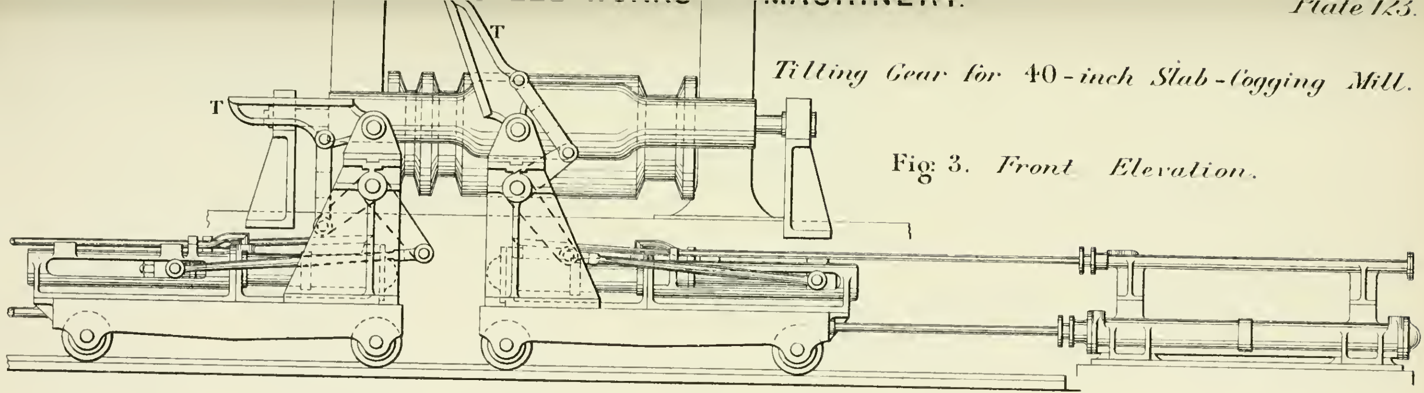


Fig: 3. Front Elevation.

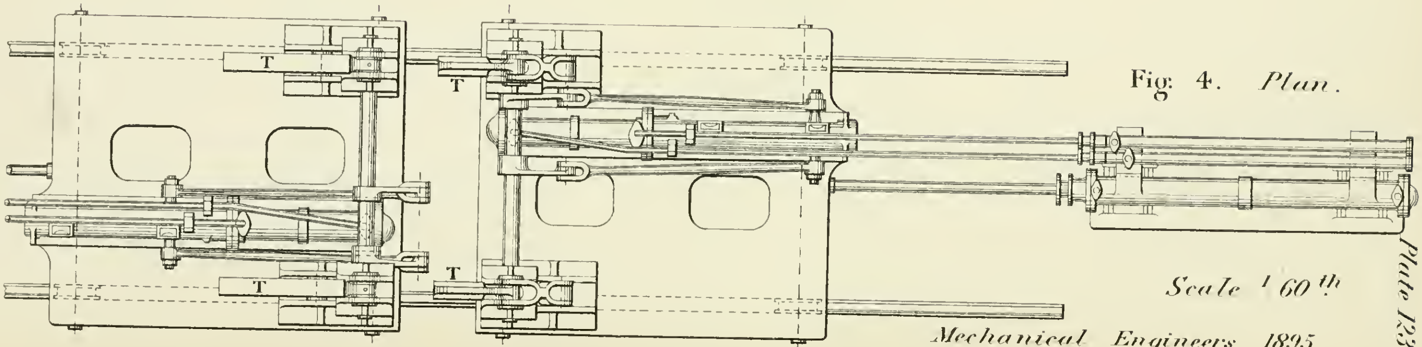


Fig: 4. Plan.

Scale 1/60th

Mechanical Engineers 1895.

Plate 123.

Ingot Tumbling Cradle for 40-inch Slab-Cogging Mill.

Fig. 5. *Side Elevation.*

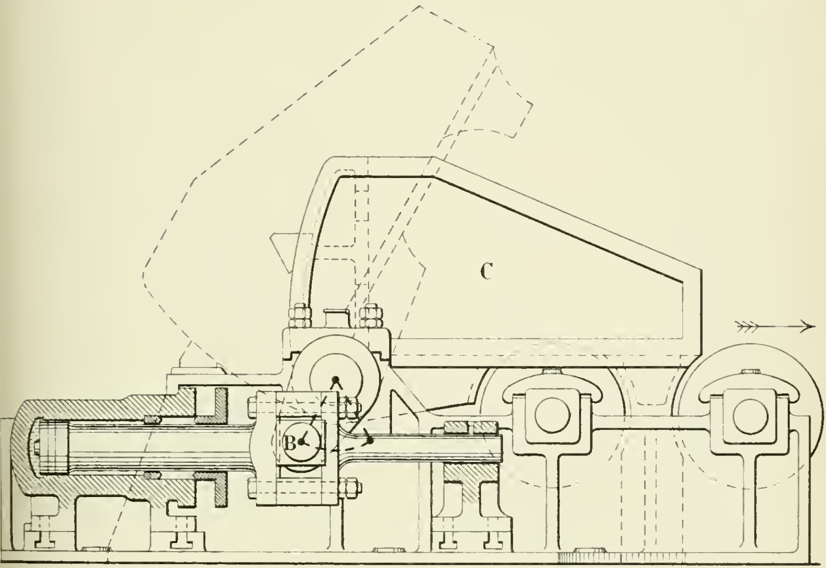
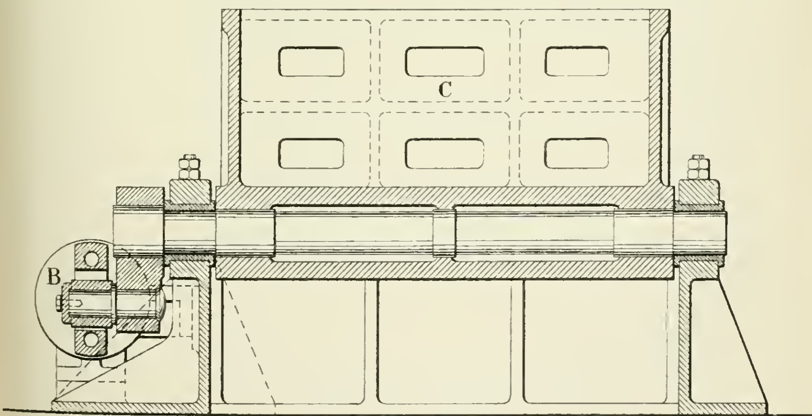


Fig. 6. *Transverse Section.*

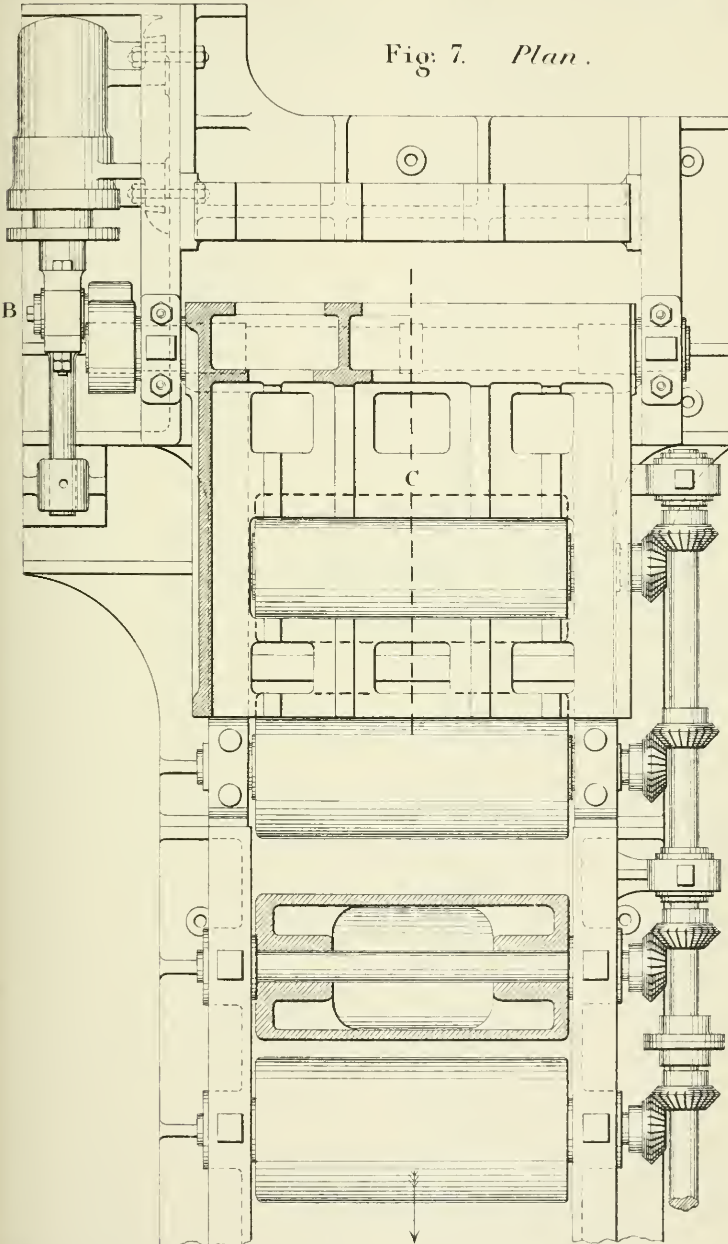


 Scale 1/32nd

Inches 12 6 0 1 2 3 4 5 6 7 8 Feet

Ingot Tumbling Cradle for 40-inch Slab-Cogging Mill.

Fig: 7. *Plan.*



Mechanical Engineers 1895. *Scale 1/32nd.*

Inches 12 6 0 1 2 3 4 5 6 7 8 Feet

Slab-Cogging Mill at Blochairn Steel Works.

Fig: 9. Back Elevation.

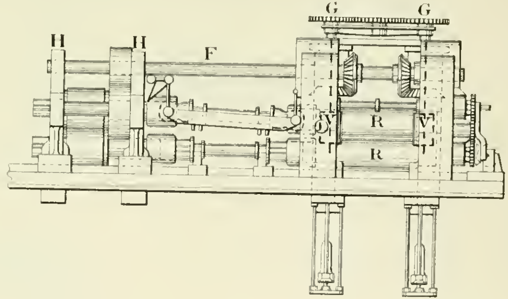
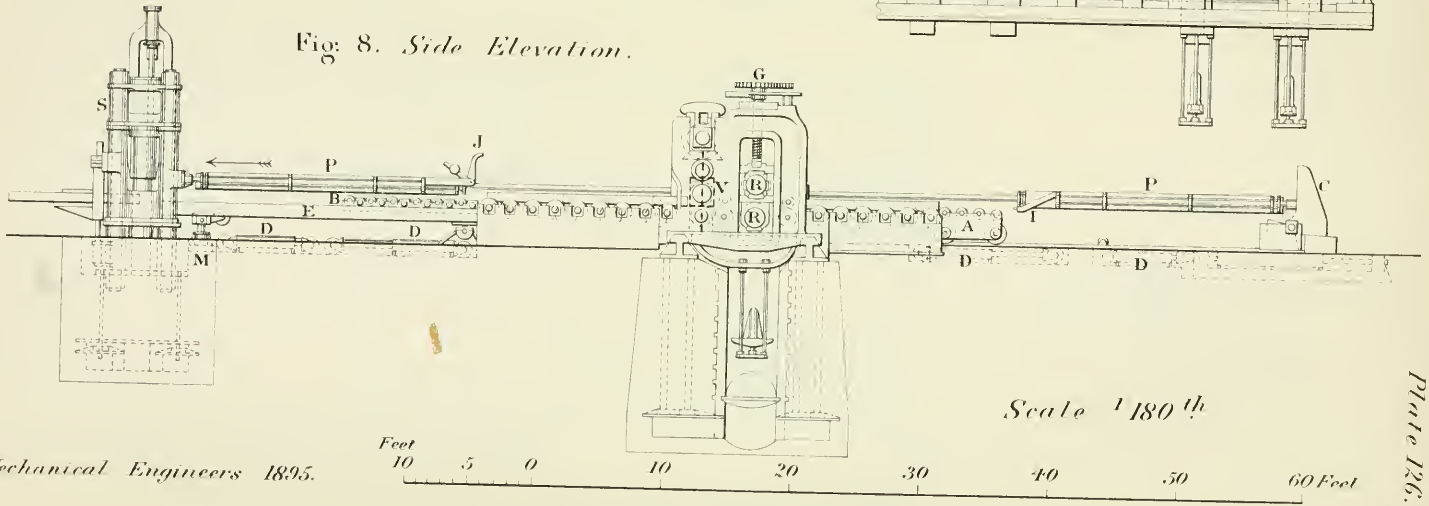


Fig: 8. Side Elevation.



Scale 1/180th

Hydraulic Slab-Shears.

Fig: 10.

Side View.

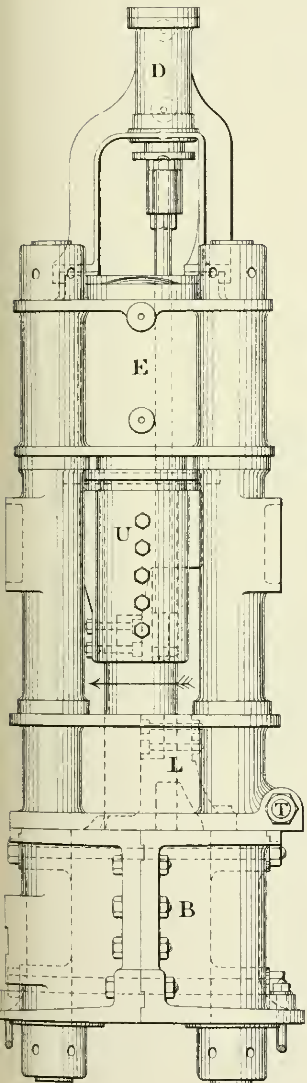
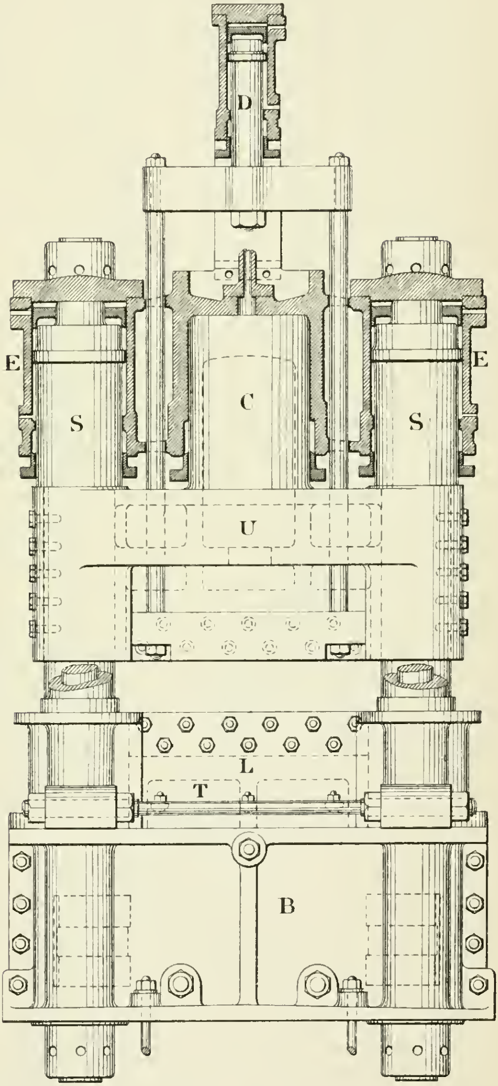


Fig: 11.

Front View.



Scale $\frac{1}{50}$th

Inches 12 6 0 1 2 3 4 5 6 7 8 9 10 11 12 Feet

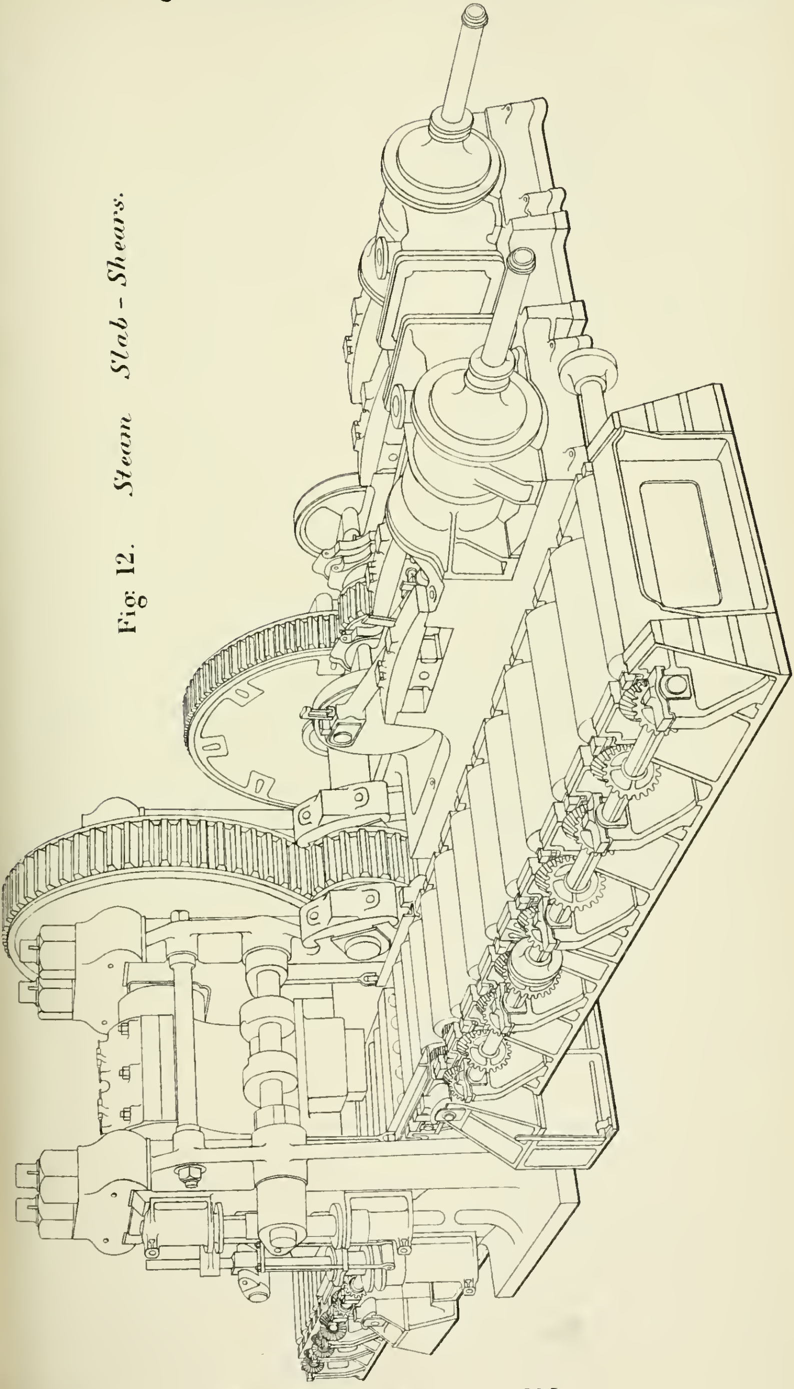
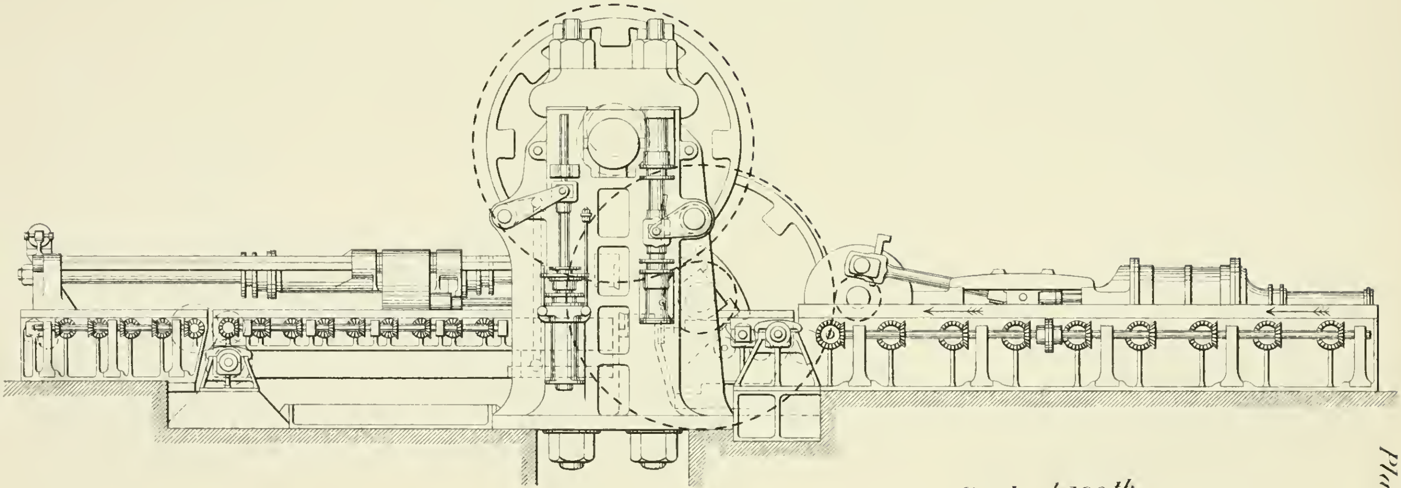


Fig. 12. *Steam Slab-Shears.*

Steam Slab – Shears.

Fig: 13. Side Elevation.



Scale 1/100th

0 5 10 15 20 25 30 Feet

Plate 129.

Steam Slab-Shears.

Fig. 14. *Plan.*

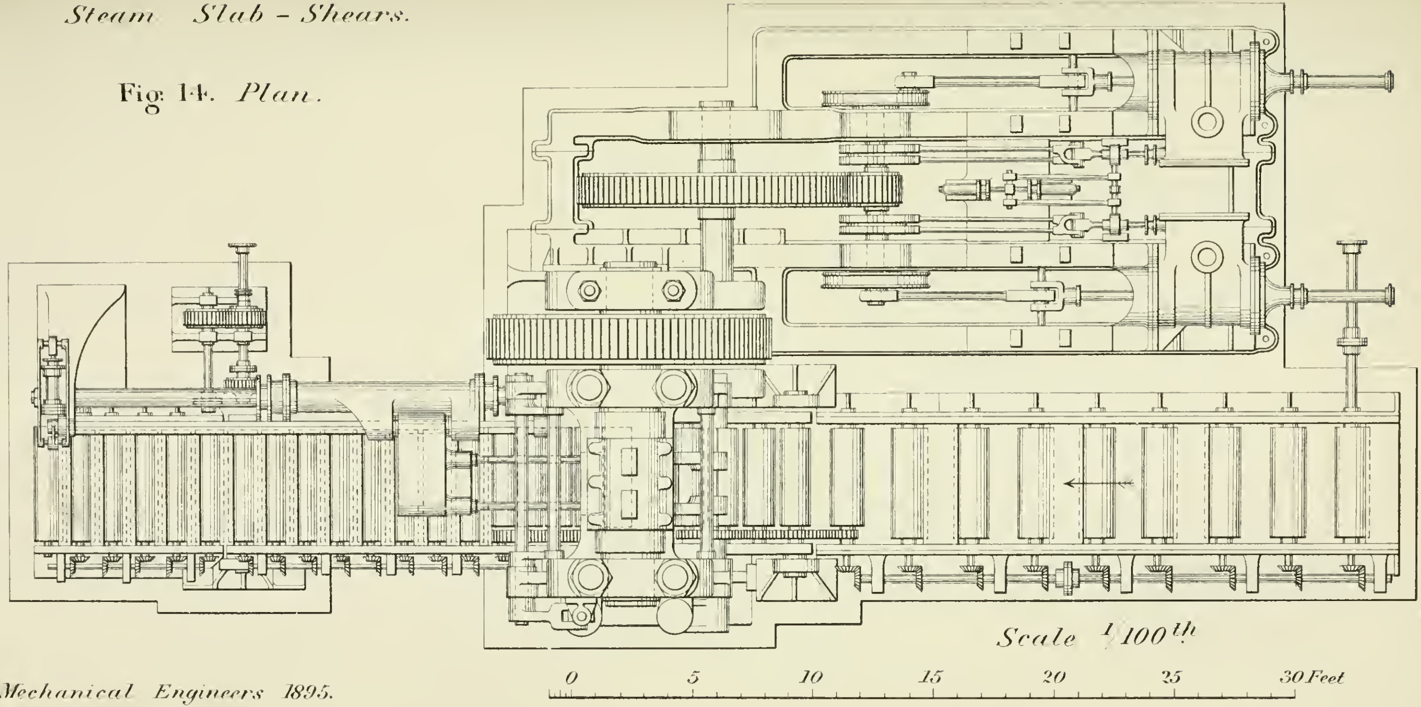


Plate 130.

Steam Slab - Shears.

Fig: 15.

Longitudinal Section.

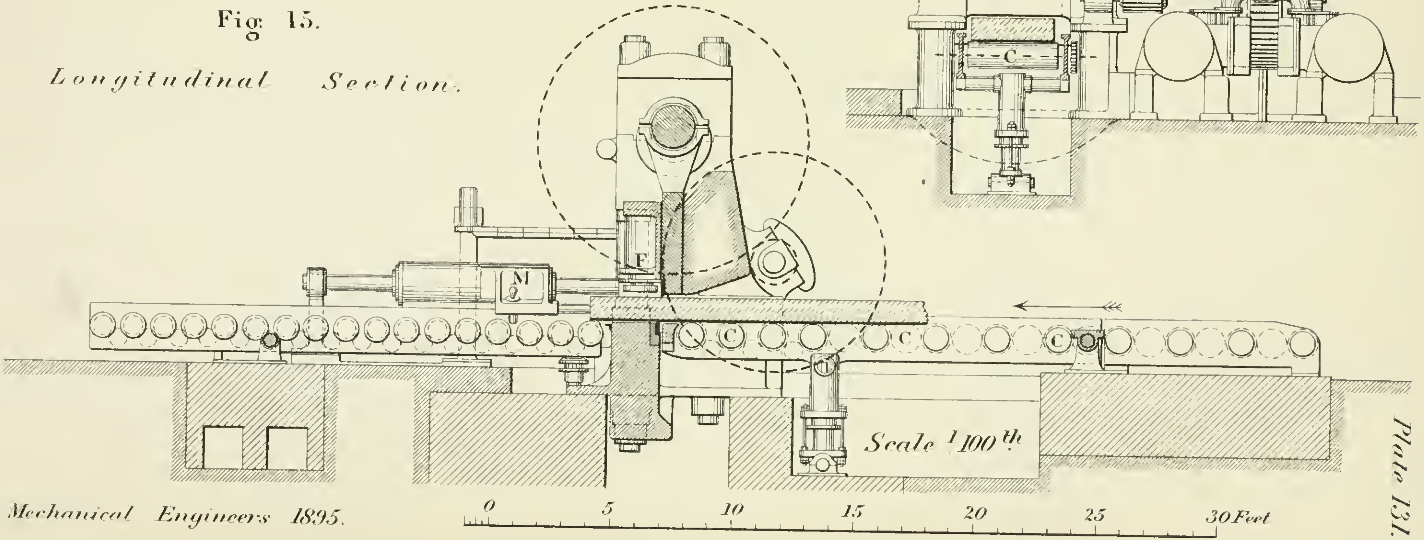


Fig: 16.

Back Elevation.

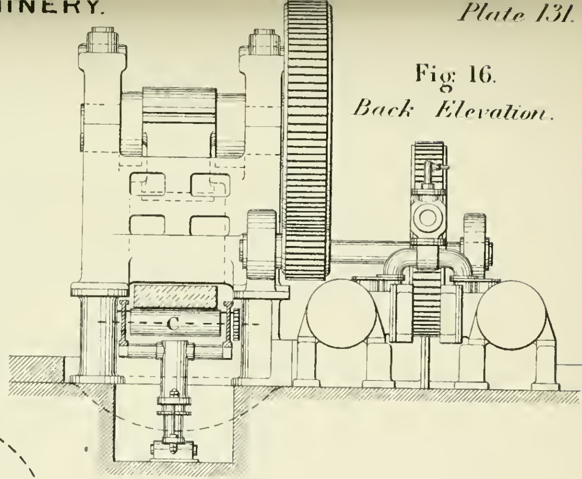
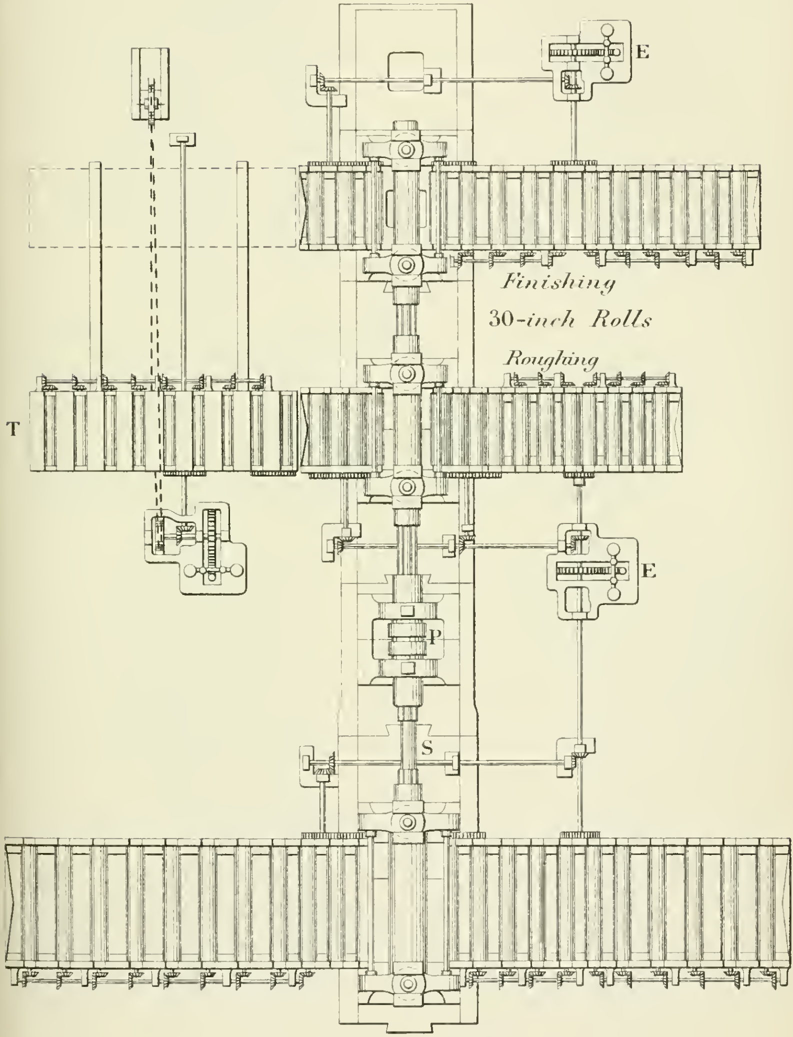


Plate 131.

Plate Mills.

Fig: 17. *Plan.*



Mechanical Engineers 1895.

Scale 1/200th.

Plate Mills.

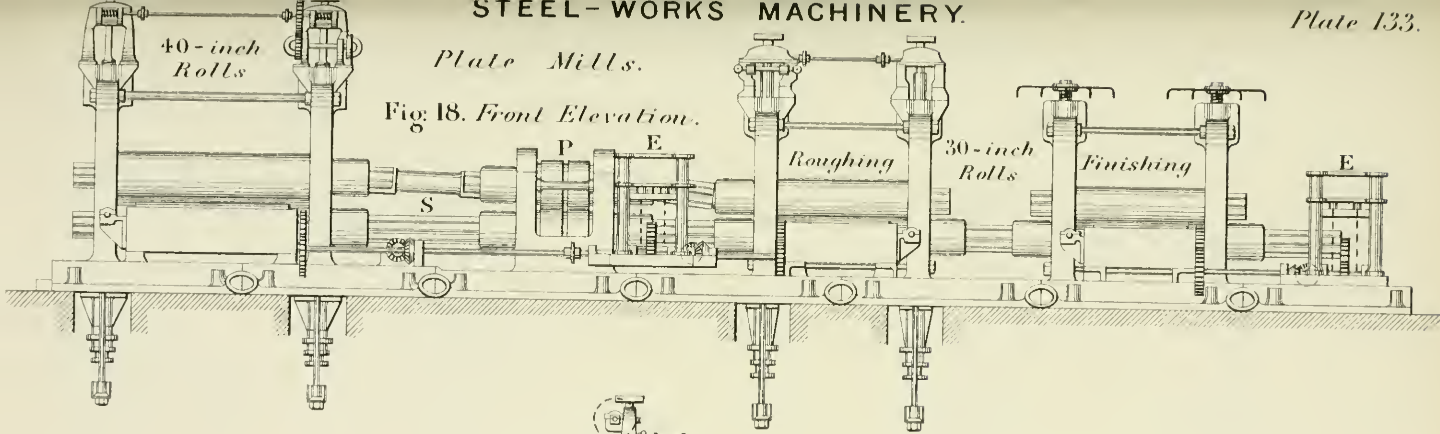


Fig. 18. *Front Elevation.*

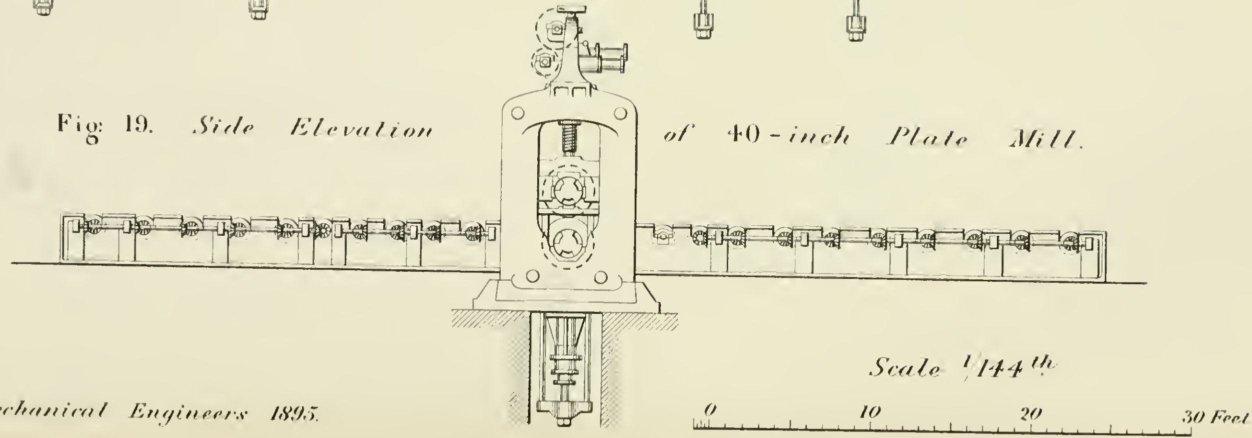


Fig. 19. *Side Elevation of 40-inch Plate Mill.*

Steam Plate-Shears.

Fig. 20. *Front Elevation.*

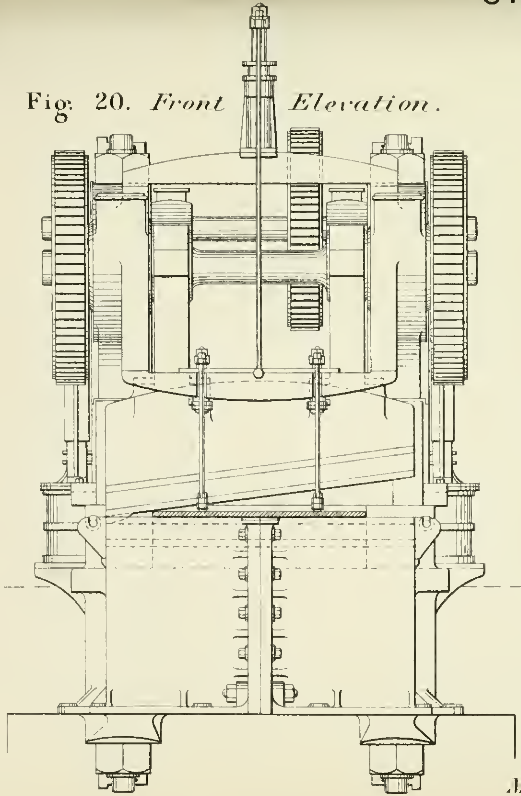
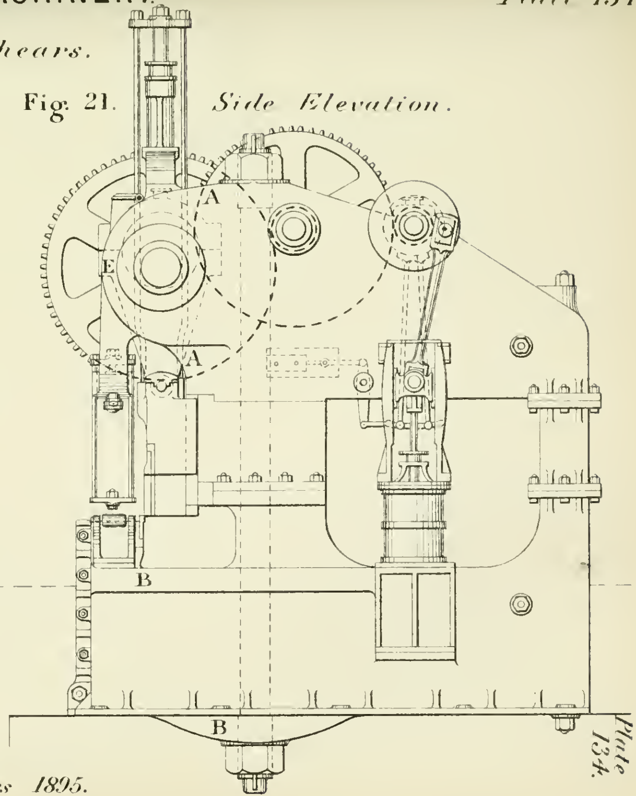


Fig. 21. *Side Elevation.*



Floor Line

Scale 1/80th

Hydraulic Plate-Shears.

Fig: 22. *Front Elevation.*

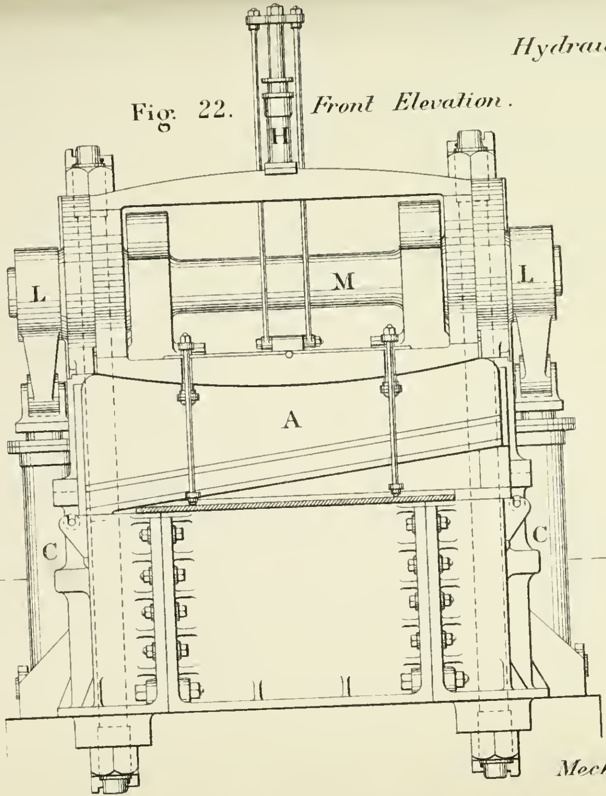
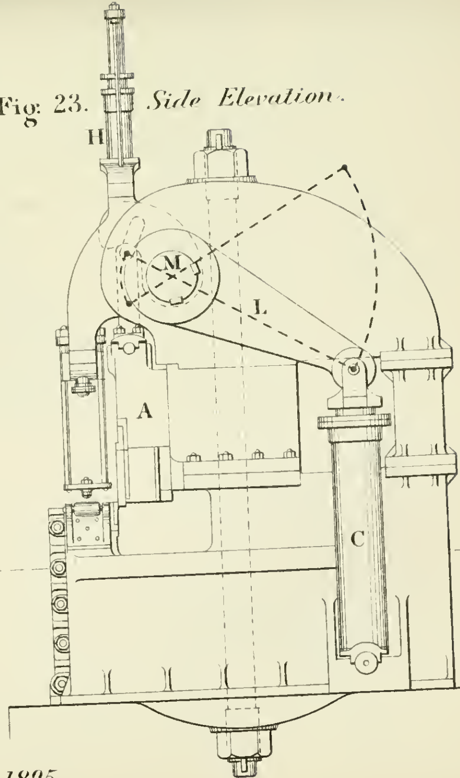


Fig: 23. *Side Elevation.*



Floor Line

Scale 1/80th

Hydraulic Plate-Shears.

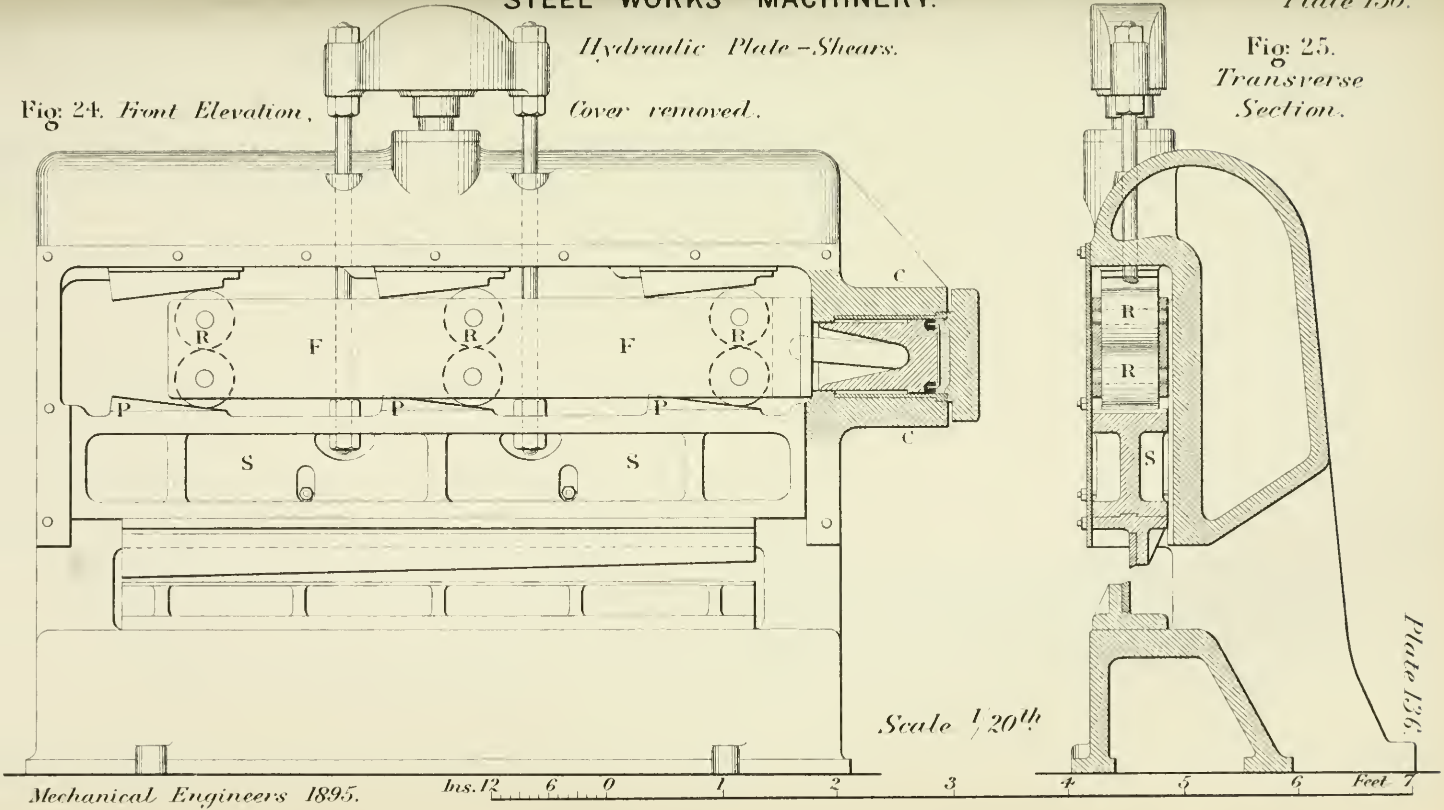


Fig: 24. *Front Elevation, Cover removed.*

Fig: 25. *Transverse Section.*

Steel Cylinder for Hydraulic Forging-Press.

Fig. 26. *Elevation and Vertical Section.*

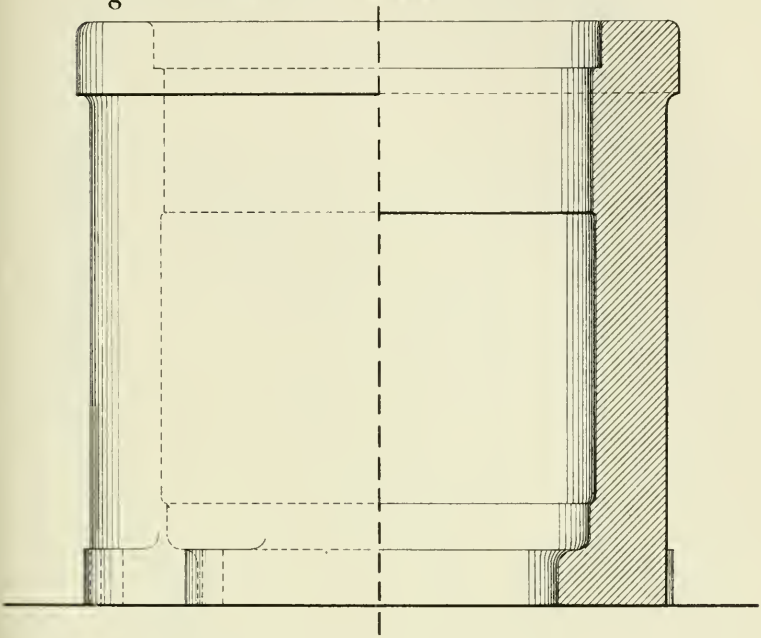
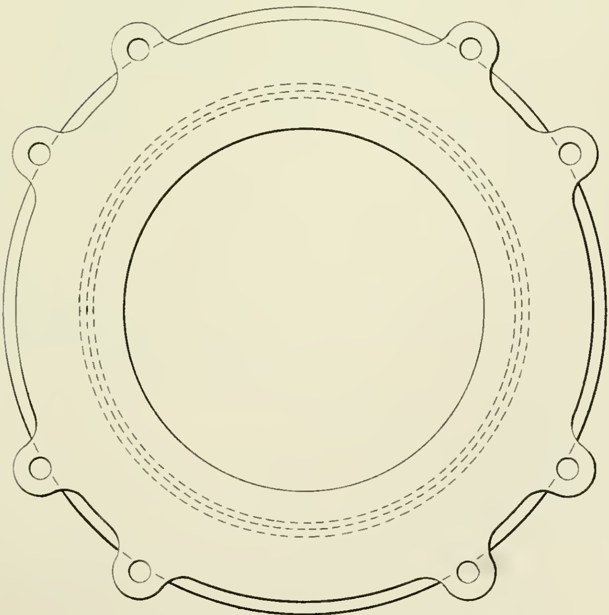


Fig. 27. *Plan inverted.*



 Scale 1/32nd.

GLASGOW WATER WORKS. *Plate 138.*

General Plan showing Line of Conduit from Loch Katrine to Glasgow.

Scale 5 miles to an inch.

Mechanical Engineers 1895.

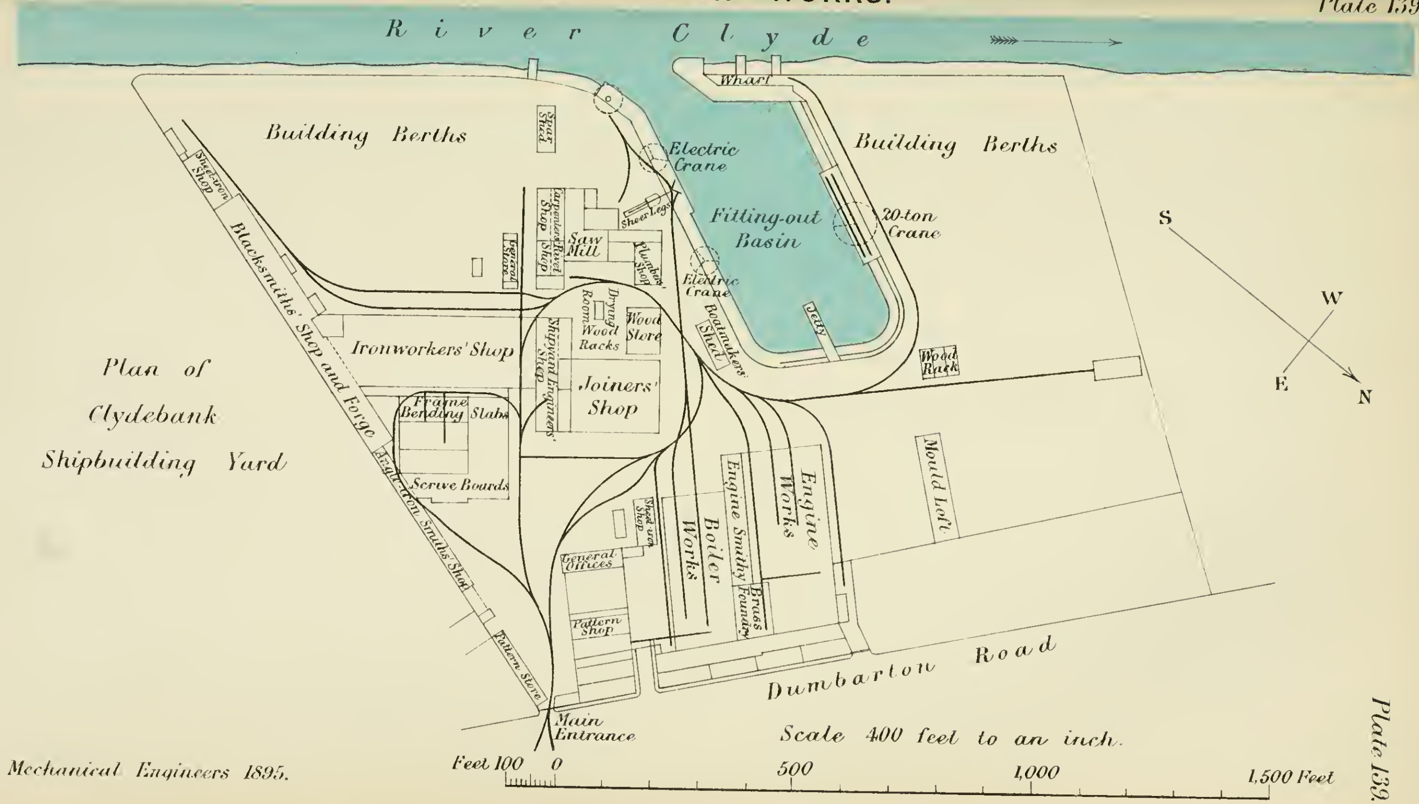

River Clyde
Wharf
Building Berths
Spar Shed
Electric Crane
Fitting-out Basin
20-ton Crane
Building Berths
S
W
E
N
Sheet-iron Shop
Blacksmiths' Shop and Forge
Sheer Legs
Carpenters' Shop
Rivet Shop
Saw Mill
Plumbers' Shop
General Store
Electric Crane
Drying Room
Wood Racks
Wood Store
Boatmakers' Shed
Jetty
Wood Rack
Ironworkers' Shop
Shipyard Engineers' Shop
Joiners' Shop
Plan of Clydebank Shipbuilding Yard
Frame Bending Slabs
Screw Boards
Angle-iron Smiths' Shop
Sheet-iron Shop
Boiler Works
Engine Smithy
Engine Works
Mould Loft
General Offices
Brass Foundry
Pattern Shop
Pattern Store
Dumbarton Road
Main Entrance
Scale 400 feet to an inch.
Feet 100
0
500
1,000
1,500 Feet

Plate 139.

Institution of Mechanical Engineers.

PROCEEDINGS.

October 1895.

The Autumn Meeting of the Institution was held in the Lecture Theatre of the Royal United Service Institution, Whitehall, London, on Wednesday, 23rd October 1895, at Half-past Seven o'clock p.m.; Professor Alexander B. W. Kennedy, LL.D., F.R.S., President, in the chair.

The Minutes of the previous Meeting were read, approved, and signed by the President.

The President announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and that the following forty candidates were found to be duly elected:—

MEMBERS.

Andrews, Thomas,	Cardiff.
Bond, George Creswell,	Nottingham.
Bratt, Edward Hicks Fraser,	Wellesley, Straits Settlts.
Buckley, Victor Emanuel,	Riga.
Carr, Robert Alfred,	Port Talbot.
Chittenden, Edmund Barrow,	West Malling.
Dewhurst, John Henry,	Sheffield.
Ellis, Arthur Devonshire,	Bradford.
Heinke, Edwin Harry Alfred,	Caracas, Venezuela.
Holliday, John,	Dublin.
James, Enoch,	Cardiff.

King, Thomas Scott, . . .	Chesterfield.
Lewis, Herbert William, . . .	Bombay.
Matthews, Thomas, ...	Manchester.
McFarlane, James, ...	Edinburgh.
Moore, William James Perry, . .	London.
Somers, Walter, ...	Birmingham.
Sprague, Ernest Headly, . . .	London.
Tannett, John Croysdale, . . .	Paisley.
Tebbutt, Sidney, ...	Leamington.
Wallace, Joseph, ...	Trinidad.
Westmacott, Henry Armstrong, . .	Newcastle-on-Tyne.

ASSOCIATE MEMBERS.

Carver, Charles Frederick, . .	Nottingham.
Corby, Matthew, ...	Birmingham.
Dronsfield, James, ...	Oldham.
Dubrule, Louis Henri Jean Baptiste, .	Lille.
Dumas, Robert, ...	Woolwich.
Greene, William Spencer Clayton, .	London.
Groves, Montague, ...	Salisbury, Mashonaland.
Hockley, Norman Julius, . . .	Burton-on-Trent.
House, Henry A., Jun., . . .	East Cowes.
Phillips, Exham, ...	Manchester.
Pugh, Charles Vernon, . . .	Birmingham.
Ridley, Clarence Oliver, . . .	London.
Williams, Henry Watson, . . .	Bristol.

ASSOCIATES.

Cole, James Conrad, . . .	London.
MacBrayne, Laurence, . . .	Glasgow.

GRADUATES.

Griffith, Charles Leopold Troyte, .	London.
Hall, William Brasier, . . .	Cheltenham.
Smith, Frederick Hardcastle, . .	Leeds.

The President announced that, in accordance with the Rules of the Institution, the President, two Vice-Presidents, and five Members of Council, would retire at the ensuing Annual General Meeting; and the list of those retiring was as follows:—

PRESIDENT.

Alexander B. W. Kennedy, LL.D., F.R.S., . . London.

VICE-PRESIDENTS.

Sir Douglas Galton, K.C.B., D.C.L., LL.D., F.R.S., London.
Sir James Ramsden, ... Barrow.

MEMBERS OF COUNCIL.

Dr. John Hopkinson, F.R.S., ... London.
Arthur Keen, ... Birmingham.
William Laird, ... Birkenhead.
John G. Mair-Rumley, ... London.
A. Tannett Walker, ... Leeds.

Of these the following offered themselves for re-election:—

VICE-PRESIDENT.

Sir Douglas Galton, K.C.B., D.C.L., LL.D., F.R.S., London.

MEMBERS OF COUNCIL.

Dr. John Hopkinson, F.R.S., ... London.
Arthur Keen, ... Birmingham.
William Laird, ... Birkenhead.
John G. Mair-Rumley, ... London.
A. Tannett Walker, ... Leeds.

The following nominations had also been made by the Council for the election at the Annual General Meeting:—

PRESIDENT.

E. Windsor Richards, . . Low Moor.

VICE-PRESIDENTS.

Election as Member.		
1865.	Francis C. Marshall, . .	Newcastle-on-Tyne.
1873.	William H. Maw, . . .	London.

Election as Member.	MEMBERS OF COUNCIL.	
1881.	James F. L. Crosland, . .	Manchester.
1873.	Henry Davey, . . .	London.
1875.	Edward B. Ellington, . .	London.
1877.	William Foulis, . . .	Glasgow.
1885.	Thomas Mudd, . . .	West Hartlepool.

The President reminded the Meeting that according to the Rules of the Institution any Member or Associate Member was now entitled to add to the list of candidates.

No other names being added, the President announced that the foregoing names would constitute the nomination list for the election of officers at the Annual General Meeting.

The following Paper was then read and discussed :—

"The Electric Lighting of Edinburgh;" by Mr. Henry R. J. Burstall, of London.

The President called attention to the Memorial which was being prepared for presentation to the Right Honourable Henry Chaplin, M.P., President of the Local Government Board, urging the repeal of existing statutes, so far as they operated to prevent the use of light vehicles, propelled by steam or other motive power, and not employed in traction. This had already been lying for signature in the reading-room of the Institution; and Members who were in sympathy with the object of the memorial, and had not yet signed it, were invited to do so at the present meeting.

At Half-past Nine o'clock the Meeting was adjourned to the following evening. The attendance was 64 Members and 68 Visitors.

The Adjourned Meeting was held at the Royal United Service Institution, London, on Thursday, 24th October 1895, at Half-past Seven o'clock p.m.; Professor Alexander B. W. Kennedy, LL.D., F.R.S., President, in the chair.

The following Papers were read and discussed together:—

"Report on the Lille Experiments upon the Comparative Efficiency of Ropes and Belts for the Transmission of Power." Translated by Professor David S. Capper, of London.

"Observations on the Lille Experiments upon the Comparative Efficiency of Ropes and Belts for the Transmission of Power;" by Professor David S. Capper, of London.

The Meeting then terminated at Half-past Nine o'clock. The attendance was 75 Members and 56 Visitors.

THE ELECTRIC LIGHTING OF EDINBURGH.

By Mr. HENRY R. J. BURSTALL, of London.

The Electric Lighting of Edinburgh, as is also the case in many of the most important towns in England and Scotland, is in the hands of the Corporation; and was finally decided on late in 1893, when the work of designing and superintending the whole scheme for public and private supply was entrusted to Professor Kennedy. Work was commenced at the station and in the streets in May 1894, and the station was opened for the continuous supply of electrical energy on 11th April 1895, the exceptionally severe winter having seriously delayed the progress of the station buildings.

Districts.—From the electrical point of view the city of Edinburgh may be said to consist of two districts, differing from each other both in character, and in their positions relative to the centre of the city, Fig. 1, Plate 140. The older part of the city by the Castle, and the district north of Princes Street, include the greater part of the business premises, together with a residential district in which the houses are large and closely built, and where the demand for current may be expected to be great. The district to the south and east of the central portion is either residential or of such a character that the demand for current can never be as large as that in the northern and central district. The residential part of this district contains many houses which stand detached from one another, thus diminishing considerably the possible number of lamps in proportion to the frontage. Having regard to the different districts to be served, and taking into account all the local circumstances, it was decided, after comparison of the various systems of supply and distribution which could be used, to adopt a low-tension three-wire system for the

central and northern district, and an alternating-current high-tension system for the southern and eastern district, both systems being worked from one central station and under the same control and management. A good site was found for the Central Station between the Caledonian Railway and Dewar Place. The foundation here is rock; and the station being on the railway, coal is brought direct into the boiler house in the railway trucks at a minimum of expense. The position of the site is such that, while being fairly central, it is in a neighbourhood where there is little chance of complaint as to nuisance, real or otherwise.

Station.

The building, which is a handsome brick erection with brown stone frontages to Dewar Place and Torphichen Street, is from the designs of Mr. J. Cooper, the Burgh Engineer, and was erected under his superintendence. The site is roughly triangular; the boiler house occupies nearly the whole of the north side, and the two engine rooms are parallel to and south of it; the general offices occupy the extreme south of the site, and are large enough for the accommodation of the whole of the clerical staff, as well as for the resident engineer and his assistants. Above the boiler room are the workshops; and the floor above the western end of the engine rooms is used for the battery room, store room, and meter store and testing rooms. The eastern part of the engine room is covered with a light iron roof, with ample provision for light and ventilation. The boiler room is covered with a concrete floor, which will ultimately be used as a coal store. There is ample space in the buildings at present erected for considerable extensions without any extra outlay beyond the foundations for new engines and boilers.

Boiler House.—The boiler house, Figs. 2 to 4, Plates 141 to 143, is 152 feet long by 46 feet wide, occupying nearly the whole of the north side of the site. It is designed to contain seventeen boilers, Fig. 12, Plate 150, of which at present only the six at the west end are in place. The main flue runs along the centre under the stoking

floor into the chimney, which is placed in the middle of the length of the house, and is 8 feet square inside and 160 feet high, being lined with fire-brick for a height of 60 feet. The side flues from each boiler enter the main flue at a slight angle, and each flue is fitted with a butterfly damper; a damper is also placed in the main flue close to the chimney.

The boilers are of the dry-backed marine type, Plates 142–3, each $10\frac{1}{4}$ feet mean diameter and 12 feet long, with two Purves flues, $3\frac{1}{4}$ feet inside diameter, and 166 tubes of 3 inches internal diameter. The boilers are of steel, with wrought-iron tubes, and have been built in accordance with Board of Trade rules for a working pressure of 160 lbs. per square inch above atmosphere. They are fitted with the usual mountings, and have duplicate feed check-valves.

On the top of the boilers are fitted superheaters SS, Plates 141–3, each consisting of two nests of tubes enclosed between the top of the boiler shell and a fire-brick casing above, with a space left in the centre for the steam-valves, safety-valve, &c. Each superheater consists of twenty-six vertical flat coils of wrought-iron tube $1\frac{1}{2}$ inch diameter, running from a large cast-iron pipe at the back of the boiler to a similar pipe at the front, all joints being outside and protected from the action of the gases. The steam circulates from a standpipe on the boiler to the back leading pipe, through the superheating tubes to the cast-iron pipe at the front, and thence to the main steam-pipe; proper valves are arranged so that the superheater can be entirely shut off and the steam be taken direct to the main steam-pipe. Each superheater is fitted with a safety-valve and draining cocks. The superheater coils are readily accessible for cleaning and examination by doors at the front and by movable plates at the top; or if necessary they can be lifted bodily away from the boiler. The course of the furnace gases is from the furnace to a brick combustion-chamber at the back of the boiler, through the boiler tubes to a wrought-iron smoke-box at the front, thence up and along the top of the boiler, past the superheater tubes to the back, and there down each side to a centre flue under the bottom of the boiler. A damper is provided, by which the gases can be sent direct

to the sides of the boiler without passing the superheater tubes. Sinclair's mechanical stokers are fitted to each boiler, and are worked from two lines of shafting, which are carried by the columns of the boiler house and driven by an electric motor.

Steam is taken from each boiler through a standpipe, with valves to the superheaters; and from the latter through a large copper bend to the main steam-pipe, which forms a complete ring round the present boilers. This ring joins the engine-room main at two points; and is provided with valves, so that the failure of any one pipe will put only the corresponding boiler out of use. Drain-valves are placed wherever water may accumulate, and are all connected to a steam-trap which returns the condensed water to the feed-tank.

The pump room is opposite the chimney, and is entirely closed in, Plate 141. It contains at present one duplex steam-pump D and two three-throw pumps PP driven electrically; each pump has a maximum capacity of 4,500 gallons per hour. The electrically driven pumps are specially designed to run with a large range of speed; and for this purpose can be connected with either the 230-volt or the 115-volt mains. The steam-pump has its steam supply connected with two points of the main steam-pipe, and its exhaust is connected with the feed-heater. Each feed-pump has an independent suction from the feed-tank, and two independent deliveries into two separate lines of pipes, each of which can be connected with either range of the two duplicate rings of feed-pipes, either through the feed-heater or direct. The duplicate rings of feed-pipes are carried round the stoke-hold in chases in front of the boilers; and each boiler is connected with both rings of pipes by separate feed check-valves delivering into a common internal pipe. A Kennedy water-meter K is connected with one range of feed-pipes, so that the whole of the water going to the boilers can be measured. In the pump room is placed the electric motor M for driving the mechanical stokers with its countershaft; and there is ample space for more pumps when they are required.

Under the pump room is the feed-tank, which communicates with a large storage tank at the end of the boiler house; another feed-tank is also provided under the workmen's room, so that there is an

ample reserve of water in case of accident to the water supply. A siding from the Caledonian Railway runs into the boiler house, and the coal brought in the railway trucks is at present stored in the east end of the boiler house ; on the station being extended, the coal will be stored over the boiler house, and let down through shoots to the mechanical stokers. In designing the plant at present in the boiler house, provision for extensions has been kept in mind ; and the arrangements are such that new plant can be added at any time, without interfering in any way with the working of that already in use.

Engine Rooms.—The engine rooms, Plates 143 to 147, are each about 102 feet long, and are side by side, Fig. 12, Plate 150, forming really one room divided by a line of columns which carry the roofs and the beams for the travelling cranes. The engine room next the boiler house is reserved for the low-tension plant, and is 46½ feet wide ; the other contains the high-tension plant, and is 41½ feet wide. A platform F, raised 4 feet above the engine-room floor-level, runs the whole way across the west end of both engine-rooms ; and on this are placed the switchboards and regulating gear for both the low and high-tension systems, as well as the office of the engineer on watch.

Low-Tension Engine-Room.—The machinery at present in the low-tension engine-room, Plates 143 to 147, consists of eight engines, four of 100 I.H.P., two of 250 I.H.P., and two of 360 I.H.P., with their dynamos ; and provision is made for eight more engines of 360 I.H.P. in the future. All are Willans central-valve engines driving their dynamos direct. All the dynamos are two-pole shunt-wound machines with drum armatures, wound to give 270 volts, with the exception of two which are driven by two 100-I.H.P. engines ; these two are wound to give 135 volts, being used as balancing machines on the three-wire system.

The steam-piping forms, with part of the boiler-house ring, a complete ring round the low-tension engine-room, Plates 141 and 146, and is connected with the boiler-house ring at two points. The main ring is 8 inches internal diameter throughout : the straight

lengths are of steel, with thick flanges screwed and brazed on; the tee pieces and valve-boxes are of cast-iron, and the bends of copper with steel flanges. All bends are of large radius, and no expansion joints are used or required. The engines are erected in pairs, and are connected with the main ring by two long copper bends, Plates 143–4 and 146–7; in the main ring a valve is placed between the branches to the two pipes, with a cross-over pipe and valve at the engines, so arranged that the engines can take their steam from either side of the valve in the main ring. The pipes are slung by long rods L from brackets fixed on the walls or columns, so as to allow free movement.

In every section of the main ring are placed two drain-valves, one connected with a drain ring, which is common to half the drains, and is connected with a large steam-trap, whereby all condensed water is returned to the feed tank. The other drain-valve is connected direct to the exhaust pipe, and is used only on emergency, or when the steam is entirely shut off from that section of the pipes. The separators on all the engines are connected to a second steam-trap, which returns the water collected to the feed tank; the drains from the cylinders, &c., are connected to the exhaust pipe. The whole of the steam-pipes and valve-boxes, as well as the drain-pipes up oo the steam traps, are covered with non-conducting composition, and special non-conducting covers are fitted on all the flanges; in fact every attempt has been made to reduce the loss by condensation in the steam-pipes, which forms so considerable an item in the losses that occur in central-station work.

All the engines are fitted with cooling pipes in the crank chambers, to which the water is carried in a line of pipe round the engine foundation-block, and taken thence to the feed-tank by a second line. Each engine is fitted with a valve on the exhaust; the exhaust steam is led by a copper bend into the main exhaust-pipe, which is carried in chases in the engine foundation-block and along the void between the block and the walls. The main exhaust-pipes are of cast-iron, and are led, through a Berryman feed-heater H in the boiler house, to the chimney, Plates 141 and 142. Only one heater is fixed at present; but provision is made for three more

when required. From the heater the exhaust steam is carried up to the top of the chimney by a vertical cast-iron pipe 21 inches diameter. Valves are provided so that the exhaust steam can be carried direct to the vertical exhaust-pipe, without going through the heater.

The whole of the machinery stands on a concrete foundation-block B, 7½ feet thick, Plates 143 to 147, which is separate from the foundations of the walls. A void 3 feet wide is left at each side of the block, which is also stopped some distance in front of the switchboard platform F, thus forming a large chamber at the west end of the two engine-rooms for the connections, &c. An 8-ton travelling crane C, Plate 147, running the whole length of the engine block, is provided in each engine-room, for convenience in overhauling, &c. These cranes are worked entirely from below by means of ropes.

Leads.—The main leads from the dynamos are drawn through curved wrought-iron pipes let into the concrete, into chases JJ in the centre of the engine foundation-block, Plates 143 to 146, along which they are carried to the chamber under the switchboard platform F. The leads from the field winding of the machines are also carried in the same manner to their regulating resistances, which are placed under the platform ; the switches for these resistances are fixed upon the handrail on the platform, in front of the switchboard, the leads from the resistances being brought up through the posts of the handrail.

Switchboard and Conductors.—The switchboard, and the whole of the apparatus for regulating the dynamos and batteries, and for the distribution of the current, are placed on the platform, Plates 143–4 and 146–7, and are directly under the eye of the engineer in charge. The switchboard consists of seven slate panels, each about 7 feet high ; and stands 4 feet from the west wall of the engine room, thus allowing ample room to do any work on the connections &c. at the back. The instruments and gear for regulating the battery are mostly placed on the centre panel, and those for the switching and manipulation of the dynamos and feeders are on the six outer slates

the connections for the positive side of the system are on the left hand, those for the negative on the right, and the middle wire is connected on the centre panel.

The arrangement of the switchboard and conductors is as follows. The feeders enter the building at a cellar under the pavement on the west side, and are brought along the wall under the platform in the form of heavy copper rods, which are carried on insulators, and pass up through the floor to their respective terminals at the back of the switchboard, and are attached to the terminals at the top of the board by cones and nuts. They are connected, through a duplex fuse and an ampère meter, to heavy vertical copper bars on the front of the slates, each bar having three holes in it, through which plugs can be inserted. The leads from the dynamos are carried in the form of insulated cable to their respective terminals at the back of the board, near the bottom; and through fuses, automatic switches, and ampère meters, are connected to vertical copper bars fixed to the front of the slates, similar and parallel to the feeder bars. The automatic switches are so constructed that the switch, after being closed by hand, is held in place as long as the current flowing through it exceeds from 15 to 20 ampères; should it fall below this, a trigger is released and the switch is automatically opened, thus breaking the circuit and preventing damage if a machine should fail from any cause. Three heavy copper "omnibus" bars are fixed horizontally at the back of the three outer slates on each side, and are capable of being connected to any of the feeder and dynamo bars of that side by means of heavy copper plugs, which are inserted through holes in the vertical bars and slates, and screw into the omnibus bars at the back, the contact being made on the front bars by a faced collar. The feeders under ordinary circumstances are all connected to the top omnibus bar, and are all in parallel. In order to connect any dynamo to the feeders, plugs are screwed into the top holes of the vertical bars corresponding with that dynamo, the brushes of the machine are put down upon the commutator, and the stop valve of the engine is fully opened so that the engine is running on its governor; the switchboard attendant regulates the electromotive

force of the machine until it is equal to that shown on the voltmeter between the top bars, and then closes the automatic switch, putting load on the dynamo by taking resistance out of its field circuit. During the whole time the machine is on circuit it is regulated by the switchboard attendant, the engine running on its governor with the stop valve full open; the engine-driver has to attend only to the running of the engines and dynamos. For the sake of economy however, the engines are run somewhat slower at low loads than at full load; after about three-quarters of the full load has been reached, the setting of the governor is altered, and the engine run at full speed. In order to take the machine off circuit, resistance is put into the field circuit until the current falls so low that the automatic switch opens; the driver then lifts the brushes out of contact, and shuts down the engine.

Balancing Machines.—The foregoing description applies only to the high-volt machines; the connections for the balancing machines are somewhat different, Plate 146. The leads for each of these dynamos are connected—through fuses, ampère meters, and automatic switches, as for the high-volt machines—to two contacts of a double-pole switch on the centre panel; and can be connected alternatively with two of three contacts, one of which is connected to the middle wire and the other two to dynamo bars on the positive and negative sides of the switchboard respectively. Thus each balancing machine can be put between the middle wire and either the positive or the negative side of the switchboard. These machines are run in exactly the same manner as the high-volt machines, and the whole of their regulation is done from the switch platform.

In the circuit of each dynamo is a registering ampère-hour meter, from which are taken readings whenever the machine is started and stopped; and the station records of the units generated are made up from these readings. Volt meters are provided, which can be connected to the terminals of each dynamo by means of multipolar switches; other volt meters are also connected, so as to show the electromotive force between any of the omnibus bars on the positive and negative sides, and also between the omnibus bars and

the middle wire. A pair of volt meters are fixed on the upper part of the centre slate, and are connected through multipolar switches, so as to show the pressure between the middle wire and the positive and negative wires respectively at any feeding point on the system; and for this purpose light wires are brought back from the feeding points. The switchboard attendant is thus able to know directly the electromotive force on the distributing mains; and regulates the electromotive force at the switchboard so as to keep this constant.

The two lower horizontal omnibus bars can be connected by plugs to any feeder or any dynamo; by this means it is possible to run any feeder or feeders at a higher or lower electromotive force than the others, should occasion arise. The same two bars are also used for testing, and for the introduction of standard instruments into the circuit of any feeder, dynamo or battery, for the purpose of checking or calibrating the switchboard instruments without breaking any permanent connections or running the circuit on temporary connections. The instrument or standard resistance &c. is connected between two of the omnibus bars, and the dynamo or feeder &c. is plugged on one of the lower omnibus bars; the current passes through the resistance &c. to the top bar, which is on the outside circuit. In the actual running of the station considerable use is made of these spare omnibus bars.

Battery.—In ordinary circumstances the two outer ends of the batteries are plugged on to the top omnibus bar on the positive and negative sides of the switchboard; but can be disconnected either by removing the plugs or by the emergency switches. One of the cells near the inner end of each battery is connected with the middle wire through the regulating switch. Save under exceptional circumstances however, the electromotive force of the whole battery in series would be much too high for the circuit; and therefore by means of a regulating switch any number up to twenty-six of the inner cells of each battery can be put in parallel with the inner cells of the other battery, thus keeping the electromotive force of the battery the same as that required at the omnibus bars to which the feeders are connected. When the dynamos are running, the battery-regulating

switch can be set so that no current is passing into or out of the battery: putting more cells in parallel will lower the electromotive force of the battery, which will then be charged by the dynamos; while putting fewer in parallel will raise the electromotive force of the battery, and cause it to discharge and thus to help the dynamos. Under normal circumstances the battery is charged while the load is light, more or less current being put into the battery as the load on the external circuit varies, so as to keep the engines running at that time as fully loaded as possible. During heavy load the battery is kept as far as possible with no current going either into or out of it; only after the dynamos are stopped is it discharged at all heavily, or when the load suddenly rises, and then only for short intervals. This method of regulating the battery by putting the centre cells in parallel, which is due to Mr. B. M. Jenkin, necessitates connecting up to the regulating switches more cells than the usual arrangement of regulating by cutting out cells on the outer ends of the batteries; but it renders the manipulation of the battery much more simple, and does away to a great extent with the somewhat troublesome charging of the back cells, that is to say the cells at the outer end of the batteries, which also in the usual arrangement may be used for only a few hours or even only a few minutes in the day, while they have always to be charged and kept ready for work.

Battery Connections.—The connections to the battery are shown on the diagram, Plate 148, whereon is roughly indicated the actual manner in which the switches &c. are arranged. The connections may appear somewhat complicated; but in actual work the regulation of the battery is effected by moving only one wheel, like a steering wheel, fixed on the middle slate of the switchboard. The switches themselves are placed in the battery room above, and are worked by wire ropes from the wheel below. A special circuit and switch is provided, by which the cells that are in parallel can be charged independently of the rest of the battery; but in actual work this is not regularly used. In this arrangement of battery regulation the whole of the cells in the battery are always used, but the centre

cells are not charged or discharged to such an extent as those which constantly remain in series. By properly choosing the time of charging, the regulating cells can receive rather more charge than they discharge; and in order to enable the charging to go on at light load, when there is only a small drop on the feeders, the "hospital" or "milking" cells are connected up, as shown in the diagram, four on each side of the system, through two small switchboards on the switch platform. By suitably arranging the switches these cells can either be put in series with the main battery, or be put between the dynamo charging the battery and the feeders; in the latter case part of the current goes to the battery and part on to the circuit. The electromotive force of the dynamo charging the battery can thus be made higher than that required at the station end of the feeders; and the battery can be charged with more of the regulating cells in series than would be possible if it was in parallel with the circuit. This arrangement has the additional advantage that full use can be made of the hospital cells, which are usually standing idle unless any cell in the battery requires assisting. When used for this last purpose, the hospital cells are cut entirely off the circuit, and are put, two in series, in parallel with any cell which shows signs of weakness during the discharge of the main battery; connections are made from the hospital-cell switchboards in the engine room to terminals in the battery room, and adjustable resistances and ampère meters are put into each of these circuits, so that the current passing from the hospital cells to the weak cell can be regulated, and is always under control of the switchboard attendant.

Battery Room.—The battery room is directly over the west end of the low-tension engine-room, Plates 143 and 147, and is reached by a spiral staircase directly from the switch platform, Plates 146–7. It has a fire-proof floor covered with acid-resisting asphalt, and is well lighted and ventilated, having windows on both sides of the room, as well as a ventilator in the ceiling. The battery consists of 132 cells of the new Crompton-Howell 31-plate type. It is divided up into two half batteries, positive and negative; and is arranged in two tiers

on four rows of stands, which are of cast-iron with wooden longitudinal bearers carrying the cells; the eight hospital-cells are arranged on separate stands. All the cells are similar, and have each a nominal capacity of 1,000 ampère-hours, the normal rate of discharge being 200 ampères. They are contained in lead boxes, and stand on glass oil-insulators upon the longitudinal wooden bearers. The 26 cells in each half nearest the middle wire are connected up by solid copper rods with the regulating switchboard, which stands directly over the main switchboard below. Provision is made for a second battery of similar size, should it be necessary in the future. In the battery circuit there is a registering ampère-hour meter between the outer end of the battery and the switchboard, so connected that its pointer goes backwards on the dial during the charging of the battery and forwards during the discharge. The mechanism is such that the pointer is 10 per cent. slow on the charge; thus if the pointer is always brought back to zero by charging the battery, 10 per cent. more current will be put into the battery than is taken out. This percentage can be altered from time to time as may be judged necessary. The regulating switchboard is connected up to the battery bars on the main switchboard, which are similar to the dynamo bars, and is also connected up to the middle wire. These connections, as well as the special connections for charging the parallel cells and for the hospital-cells, are carried in the form of bare copper rods by insulators on the engine-room wall to their respective terminals. The battery has ample capacity to meet the whole of the load of the station from daylight till the evening; thus during the summer time it can do the lighting during more than half the whole twenty-four hours.

High-tension Engine-Room.—The high-tension portion of the station consists at present of only two engines and alternators A with their switchboard, Plates 144 and 145, and the rectifiers R for arc-lighting with their regulating arrangements and switchboard; but in the immediate future this plant will be considerably extended. Each of the alternators A is driven direct by a Willans three-crank engine

of 150 I.H.P. on the same bedplate. The alternators are of the "Portsmouth" type, with some modifications necessary owing to their increased speed of 450 revolutions per minute. Their armatures are stationary, and are of great strength; the core, consisting of sheet-iron segments, is solidly bolted into the framing of the machine, with the coils threaded through holes in the sheet iron, well insulated, and completely enclosed in brass boxes. The field magnets revolve, and consist of two heavy cast-steel discs, having on their circumference claws projecting sideways alternately over the field winding, which is between the discs and is well protected from injury. The exciting current is taken from the low-tension switchboard at 230 volts, and is only a few ampères. The alternators work at an electromotive force of between 2,000 and 2,200 volts with a frequency at present of $52\frac{1}{2}$ complete alternations per second. The main leads from the alternators, which are concentric, as well as the leads for the exciting current, are taken to the switchboard in chases similar to those in the low-tension engine-room. The arrangement of steam, exhaust, and drain pipes is similar to that already described for the low-tension engine-room.

Switchboard.—The switchboard stands on the switch gallery, Plates 144 and 145, and is built up of slabs of slate, forming shelves projecting from the west wall of the engine-room, and divided up into compartments for each alternator and circuit by slate partitions. The outer pole of each circuit and each alternator is connected to an earth plate at the station, the whole of the rest of the system being insulated from earth; owing to this arrangement all the switching can be done on the inner pole, which renders the switchboard and its manipulation very simple. The inner pole of each alternator and each circuit is connected to two similar switches through ampère meters and fuses, and can by these switches be connected to either or both of two omnibus bars at the top of the switchboard. In this way any alternator and any circuit can be connected, and the system can be worked at two different electromotive forces if necessary. The primary object of this arrangement however is to enable a machine to be thrown into circuit rapidly, by running the machine up to

full volts on one omnibus bar, and changing circuits over from the other omnibus bar, on which the other machine is running, without having to synchronise the second machine; the two omnibus bars can then be synchronised, the alternator and circuits changed over at leisure, and all the circuits and alternators run in parallel. In the outer circuit of each alternator is connected a registering watt-hour meter for measuring its output. Volt meters are connected between both of the inner omnibus bars and the outer omnibus bar; and duplicate synchronising transformers with lamps and switches are provided between the two inner omnibus bars. In the exciting circuits are ampère meters and regulating resistances, the switches of which are placed opposite the switches and ampère meters of their respective machines. At present the switchboard is arranged for only two alternators and two circuits; but it can be readily extended when required, the gear for new circuits extending in one direction, and that for new alternators in the other. The two circuits are at present connected only to the rectifiers for arc-lighting.

Rectifiers.—Opposite to the alternators, and standing on the same foundation block, are placed the Ferranti rectifiers R for the series arc-lighting, Plates 144 and 145. These are three in number, one for each of the two circuits, and one to spare. They each consist of a self-regulating transformer, of which the primary winding is connected to the omnibus bars of the high-tension switchboard, and the secondary winding is connected through a commutator and distributing switchboard to the arc-lamps. One winding is hung on knife-edges in a frame, and is capable of movement nearer to and further from the other; this automatically keeps the current in the secondary winding constant at 12 ampères, varying the electromotive force to suit the number of lamps in circuit. The current from the secondary winding of the transformer is then changed, by a commutator driven by a synchronous motor, from an alternating current to a uni-directional pulsating current, which is distributed to the lamps. A small distributing switchboard is placed at I, Plates 144–5, close to the rectifiers, by means of which any rectifier can be put on to either of the high-tension omnibus bars, and either

circuit of arc-lamps can be put on to any rectifier; and provision is made on this switchboard for extending the number of arc-lamp circuits.

Schedule of Machinery and Plant in the Station.—In the boiler house, Plates 141 to 143, are six boilers of 10 ft. 3 ins. mean diameter and 12 feet length, each estimated to evaporate actually 10,000 lbs. of water per hour; all fitted with superheaters and mechanical stokers; contractor, Mr. G. Sinclair, Leith. One duplex steam feed-pump. Two electrically driven feed-pumps.

In the engine room, Plates 143 to 147, the low-tension plant comprises eight Siemens dynamos: two have each an output of 450 ampères at 135 volts; two of 220 at 275; two of 600 at 260; and two of 865 ampères at 260 volts. The contractors for the engines, dynamos, steam and exhaust piping, feed-pumps, heaters &c., were Messrs. Siemens Brothers and Co., who also supplied the switchboard and all connections.

The high-tension plant in the engine room consists of two alternators, Plates 144 and 145, each having an output of 40 ampères at 2,100 volts; a high-tension switchboard; and three rectifiers for arc-lighting, with switchboard. The contractors for the whole were Messrs. S. Z. de Ferranti.

In the battery room, Plates 143 and 147, are 140 Crompton-Howell 31-plate cells, for which the contractors were the Crompton-Howell Electrical Power Storage Co.

Mains.—In the three-wire system of distribution for the northern and central districts, the electromotive force between the two outer conductors, positive and negative, is 230 volts, while that between the middle wire and the positive or negative is 115 volts. The latter is the electromotive force of the lamps on the consumers' premises, no trouble being now experienced in obtaining glow-lamps to work at this electromotive force, or even higher. Distributing mains are laid throughout the streets marked by fine full lines in the map, Plate 140; all three wires are laid in those streets where the demand for current is large. In the other streets the positive and middle wires are laid

on one side of the street, the negative and middle on the other; and a spare way is left on each side for a third conductor, should the demand require it. The distributing mains are all in parallel, and are connected up throughout the system; rings are completed wherever possible, so as to ensure equality of pressure, and to admit of disconnections being made without interrupting the supply.

Feeders.—The feeders from the station, which are marked by fine dotted lines in the map, Plate 140, are connected to the distributing mains at sixteen points. They consist of two conductors only, the positive and negative; the middle wire is inter-connected throughout as much as possible, and is brought back from three districts on the system. The cables are put in parallel at the station, and one connection only is made to the switchboard. The positive and negative sides respectively of all the feeders are put in parallel at the switchboard; but any feeder or feeders can be put on a separate machine if required.

Balancing.—As far as possible, consumers in each street and district are balanced against one another by connecting them alternately between positive and middle wires and between negative and middle wires; large consumers have all three wires taken into their premises, and their lights balanced against one another in a similar manner. But however carefully this balancing is done, it is impossible to get a really accurate balance; the "out of balance" current varies from hour to hour and even from minute to minute, and is different on different days of the week. The amount out of balance is compensated for at the station by means of the balancing machines, either of which can be put on either side of the system; the balancing during the light load is done from the battery alone. Light wires, forming potential leads or pilot wires, are brought back from all three conductors at each feeding point, and are connected to the feeder volt meters on the switchboard: so that the pressure at the feeding points at any part of the system is directly known at the station, and the necessary regulation made for keeping the

electromotive force constant. The distributing mains are brought back to the station, but are used only for the supply of light and power there; no regulation is done on the mains anywhere, except to the feeding points.

High Tension.—No high-tension feeders or distributing mains have yet been laid. They will be laid as concentric cables in ring circuits, and banked transformers in small sub-stations will be used wherever advisable, while houses in districts where the lighting is scattered will be served by isolated transformers. The concentric cables will be pulled into Doulton stone-ware casings under the footways, and into cast-iron pipes under the roadways. The casings have already been laid in those streets which have been opened up for the low-tension mains; and the work of laying the high-tension mains in the southern and eastern districts is now being proceeded with.

Roadwork.

Distributing Mains.—Practically the whole of the distributing mains are laid as cable insulated with india-rubber, heavily braided, drawn into Doulton stone-ware casing under the footways, and into either Crompton-Davis cast-iron casing or cast-iron pipes under the roadways, Plate 149. At all crossings, and at intermediate places on the footways, brick junction-boxes are built for the purpose of drawing in, connecting, and testing. Smaller brick service-boxes are provided at suitable intervals, where connections are made to consumers; but for this purpose, when space is limited, a special length of Doulton casing is provided, which is so made that it can be easily split longitudinally and removed; the house connection is then made with vulcanised joints, and the casing replaced and jointed up with a special collar and bitumen cement. The collar is provided with a socket, into which the pipe carrying the house connection can be jointed. A mark is made on the kerb to indicate the position of the service-box; and the pavement is then replaced. These service-boxes are found to be of great use, owing to the number of cellars under the pavement. The brick junction-boxes are covered with a cast-iron

frame, which is fitted with a cast-iron cover filled in with concrete, a water-tight joint being made with the frame. In most places the bottom of the box is filled in with dry rubble, so as to form a drain for any water which may find its way in; but where water has been found in the soil, the bottom of the box is concreted, and the whole made water-tight. Where it has been necessary in some places to put junction-boxes in the road, they have been made as water-tight as possible, and covered with a double cover, the upper being a heavy cast-iron cover with wood blocks let into it. Boxes in the road have been avoided as much as possible, as it is found so difficult to make a satisfactory job of them. In a few places the distributing mains have been laid as bare copper strip, carried on stone-ware insulators in concrete culverts.

Feeders.—Wherever sufficient space has been found under the footways, the feeders have been laid as bare copper strip, carried on stone-ware insulators in concrete culverts. Across all roads, and where there has not been sufficient space for culvert, the feeders are laid in Siemens armoured cable, laid direct in the ground with a tarred board over them to act as a protection to them and as a warning to any workmen opening the ground. The cable has everywhere been laid of greater section than the copper strip in the rest of the feeder, so that the capacity of the feeder can be largely increased, and yet the resistance be kept right, by pulling in additional copper strip into the culverts, without bringing the current density up to any excessive amount in the portions laid in cable. Thus the feeders can be made to carry considerably more current than that for which they are now designed, with the same drop of electromotive force, and without either disturbing the streets or over-running any of the cables. All the feeders have been designed to have a total drop of 44 volts at full load. In the culvert the copper strip is laid in lengths of about 20 yards, with a brick inspection-box at each joint; so that the culvert can be easily seen by means of a lamp pushed into it, and the strip can be readily drawn out and in, as required. The joints are made by tinning the ends of all the strips, and clamping them together by a gun-metal grip-box with

two $\frac{5}{8}$-inch bolts; at the feeding points the feeders are connected to the mains by short pieces of cable. Everywhere the culvert is kept quite straight in plan, but with a fall towards every junction-box or inspection-box. The strip is in no place lower than 2 feet below the level of the pavement; for it has been found elsewhere that it is impossible properly to inspect or do any work to culverts which are constructed at any great depth. There is nowhere any culvert under a roadway.

Potential Leads.—These lines, by which each feeding point is connected back to the station, consist each of three sets of wires, insulated with specially prepared paper, laid up together, and covered with the same material, a lead tube being drawn over the whole. These leads are drawn into special ways, either in Doulton stone-ware casing or cast-iron pipe, laid alongside the culverts; and are joined up into one length back to the station. The joints are made in a brass tube, soldered on to the lead sheathing, and containing insulating oil; the wires are kept separate from one another by fibre discs.

Connections.—The whole of the cable connections are made by cone connectors, sweated on to the cables, and fitting into gun-metal connecting-blocks, Fig. 11, Plate 149. The cones are all the same size for all sizes of cable, and are interchangeable; when the section of cable exceeds 0·7 square inch, two cones are used; the taper employed is one in eleven, which makes a good fit and is yet readily disconnected. The cone connecting-blocks are made in four sizes, having severally two, three, four, or five holes bored in them. The holes are bored conical to fit the cones on the cable connectors; and the blocks are interchangeable with one another. The armoured cables, which are all of large section, have special connectors sweated on to them, and these have either one or two of the standard conical holes bored in them; the connections to the distributing mains are then made by one or more short lengths of cable having cone connectors at each end. Enough slack is left in the boxes to allow the ends of the cables to be turned upwards; they are then connected together by slipping the connecting-block on them, and

the cones are drawn tight into the holes by means of a nut fitting upon a ⅝-inch screw on their ends. In order to obviate any trouble from end leakage through water dripping on the bare terminals, and also to minimise the risk of short circuits through accidental contact between the blocks, stone-ware caps are dropped over the connectors, and entirely cover all bare metal.

Public Lighting.—The streets bordered by thick dotted and thick full lines in the map, Plate 140, are lit by electricity, by means of altogether 176 public arc-lamps. In the streets bordered by thick dotted lines the arc-lamps are run four in series off the distributing mains shown by fine full lines; and each series of four is provided with a fuse, switch, and line resistance. Each lamp in the series is also provided with an automatic device, which, in the event of the lamp failing, cuts it out and introduces into the circuit a resistance equal to the lamp, so that the other lamps in that circuit are not affected. The lamps in Princes Street are constructed for a normal current of 15 ampères, and all the other low-tension lamps for 10 ampères.

In the streets bordered by thick full lines, in which no low-tension mains are laid, the lamps are run on special high-tension series-circuits from the rectifiers at the station. There are at present two series-circuits, both of which are laid in all the streets lit by high-tension lamps, and the lamps are connected alternately to each circuit. The circuits are laid as concentric cable drawn into cast-iron pipes, the outer conductor of the cable being insulated. There are twenty-four lamps on each circuit, each provided with an automatic cut-out in case of its failing to act; and also with a switch in the pillar, by which it can be entirely disconnected from the circuit if necessary, while the switch is so made as to complete the circuit for the other lamps.

In arranging the circuits for the arc-lamps, care has been taken to put alternate lamps on separate circuits in all streets, whether run from the distributing mains or from the series circuits. This minimises the risk of any street being left in darkness by the failure of any circuit; and also allows half the lamps to be switched off at or

about midnight, still leaving the streets well lighted. The arc-lamps are of Crompton-Pochin type, and are fitted with 18-inch spherical globes. They hang from the bracket of a cast-iron pillar, the centre of the globes being 23 feet above the level of the pavement. In Princes Street the lamps are about 45 yards apart, and are on one side only of the street. In the other parts of the city the lamps are about 60 yards apart, and are placed alternately on the two sides of the street.

No contractor was employed for the roadwork or laying of the mains; the whole of this work, including the erection of the arc-lamp posts, was carried out by the Resident Engineer, Mr. E. W. Monkhouse, with his own staff of workmen. The armoured cables were supplied by Messrs. Siemens Brothers and Co.; the unarmoured cables by the Henley's Telegraph Works Co., and the India-Rubber Gutta-Percha and Telegraph Works Co., Silvertown. The potential leads were supplied by the British Insulated Wire Co. The stone-ware casing was manufactured by Messrs. Doulton and Co., and the cast-iron work by Messrs. Maclaren and Messrs. Shaw and Co. of Glasgow. The copper strip was supplied by Messrs. Bolton and Co. of Oakamoor Works. The posts for the arc-lamps were designed by the Edinburgh School of Art, and the castings were made by Messrs. Mackenzie Brothers of Edinburgh. The whole of the arc-lamps were supplied and fixed by Messrs. Crompton and Co. of Chelmsford, who also supplied the cable-cones and connectors.

In this account of the electric lighting of Edinburgh the author has endeavoured to describe the arrangement of the plant and mains, and any details in their design and construction which may be of interest, without discussing general principles or the advantages or disadvantages of any individual system. Having himself had the good fortune to be connected with this particular work from its earliest stage to its opening, he desires to express his deep indebtedness to Professor Kennedy for permission to prepare the present paper and to use the drawings from which the illustrations have been prepared; and also for his suggestions and assistance, without which it would have been impossible for this paper to be laid before the Institution.

Discussion.

Mr. Burstall drew attention to specimens brought from Edinburgh by Mr. Monkhouse, the Electrical Engineer to the Edinburgh Corporation, of cone connecting-blocks, cable joints, and stone-ware caps; and also to photographs of the low-tension engine-room and switchboard, and of the alternators and rectifiers. A collection of Doulton casings was lent by Messrs. Doulton and Co., containing two, three, and four ways; also connection boxes with three and four ways; jointing mandril for casings, and joint mould for two-way casing; and two-way and three-way insulators.

Mr. William H. Patchell, Chief Engineer of the Charing Cross and Strand Electricity Supply Corporation, asked why alternators were put in for the outlying districts (page 553). It appeared to him that the work might have been done just as well, and probably better as far as the load factor of the station was concerned, by putting in continuous-current transformers to be worked at hours of low load, and high-tension direct-current machines for the feeders at the high loads, when it was worth while running separate machines. In that way it seemed to him there would have been a chance of getting a really good load-factor.

The question of electrical pumps (page 555) was also one in which engineers were all much interested at the present time, in view of the notorious inefficiency of the ordinary duplex pumps, than which he thought nothing could well be better as steam eaters, while certainly as pumps they might be much worse. They were always ready when called upon, and from this point of view should be given credit for having done yeoman's service. But when it came, in these days of close competition, to sitting up all night in order to save a fraction of a penny per unit, it had to be considered whether electrical pumps were not cheaper. From whichever side the question was regarded, whether from the steam side or the electrical side, he thought it could be proved with equal satisfaction that either pumping was as cheap as the other. He asked how the load was divided

on the pumps so as to get a good load-factor on the motors. There was an arrangement he noticed for connecting the pumps with either the 115-volt or the 230-volt mains; but even then, how did the actual working of the pumps come out in efficiency? At this early stage it might be too much to ask whether the electrical pumps were really cheaper than steam pumps in their working, but it would be interesting to learn this, if it had yet been ascertained.

The matter of superheating (page 554) was one he had been much interested in for the last two years, having adopted the system for more than that period; and he was glad to find that other stations were going in for it. Were there any figures to be had with regard to the testing of the superheater as it now stood? The shape of the pipes in the present arrangement seemed to him not altogether satisfactory, for he thought there must be a good deal of wet in them, and he did not quite see how that wet was going to pass through, or whether the superheater would not be acting rather as only a sort of water-trap. With ordinary stoking the temperature of the flue gases would be 750° or 800° Fahr. at the outside; and he enquired how many pipes went to make up the superheater for each boiler, whether thirteen or twenty-six.

The President replied that there were twenty-six superheating pipes to each boiler, thirteen on each side.

Mr. Patchell had had no experience of superheating at the engine stop-valve. All he had used superheating for was to overcome the condensation in the steam pipes. Eventually he hoped to carry out superheating at the engines, but he had not got so far yet. The superheaters he was using were applied only to two boilers out of seven, the other five not being fitted with any superheating apparatus; and in the ring of steam pipes he could get by this means about 10° superheat in the steam; but this practically counted for nothing at the engines.

Mr. Bryan Donkin, Member of Council, asked whether superheating had been tried at the Edinburgh station for any length

(Mr. Bryan Donkin.)

of time, and what was the average temperature in the smoke flue outside the superheating tubes, and also the degree of superheat over and above the temperature of the saturated steam.

Mr. William Geipel, Superintendent Engineer to the Brush Electric Engineering Co., said that in so complete and detailed a description of the Edinburgh Central Station he should have been glad if some information had been given both as to the cost of the undertaking, and as to the tests and efficiencies of the various portions of the machinery. Like the last speaker he was curious to know what was the amount of superheating obtained from the flue gases after they had passed through the boiler tubes. There was no doubt that it was an excellent thing to superheat the steam, in order to compensate for the heat lost between boiler and engine; but it seemed to him that, when the superheater tubes became coated with soot, the passage of heat through them would be comparatively small, owing to the low temperature of the flue at that point. It was true that, whilst the boilers were being forced, the flue temperature would be somewhat higher beyond the boiler tubes; but better results in superheating could be obtained if the heater were situated in a flue where high temperature was always available. It was also to be remembered that there was more necessity for superheating at light loads, because the velocity of the steam in the pipes was then lower, and consequently the loss by radiation per pound weight of steam was greater, while conversely there was less heat available in the flue for superheating. A certain amount of superheating could be obtained, as was well known, by working boilers at a higher pressure than the engines were worked at, and throttling the steam at the stop valves of the boilers or engines. In that way some objections in the working of superheaters were got rid of, such as the deterioration of the superheaters themselves, which he believed was somewhat rapid. Certainly a higher boiler-pressure did not give a high degree of superheating; but it might give a sufficient amount to supply at any rate dry saturated steam to the engines.

The drain-valves he noticed (page 555) were all connected to a common steam-trap, thereby necessitating the use of a non-return

valve at each drain, and increasing not only the number of valves requiring attention at starting, but also the number of high-pressure joints and the extent of radiating surface; the last especially was a matter of serious consideration in an electric lighting station. His experience was that it was better in every way to apply a separate steam-trap at each point. The trap should be of the open kind, that is, the valve should be always open, except when dry steam attempted to pass. If in turning on steam it were known that each drain was naturally open, and that each would close whenever there was only dry steam to pass, the attendant's duties would obviously be lightened. More especially was this an advantage in case of a sudden emergency, when all possible time should be saved.

The plan of using electric motors for driving the mechanical stokers and feed-pumps was one which he could recommend from experience. Small steam cylinders driving feed-pumps were proverbially wasteful; and as to slow-running direct-acting steam feed-pumps, they were simply steam eaters, and should on no account be used, except as stand-by pumps. Where steam was used at all for continuous boiler feeding, it should undoubtedly be through the medium of a quick-running engine with early cut-off, geared indirectly to the pump.

It would be interesting to know why one of the several sources of water in Edinburgh had not been utilised for condensing. In central stations he had found condensing most economically applied, more especially to the engines which were most in use.

In regard to the use of steel flanges on the copper bends in the steam pipes (page 557), he asked whether the flanges were of cast malleable steel. If they were, he understood there was a tendency for electrolytic action to take place, which in the course of years affected the joint; and he should be glad to know whether this had been found not to be the case, even after many years of use.

In the steam pipes he should expect vibration to take place, if they were merely slung by long rods (page 557) without being stayed at one or more points.

(Mr. William Geipel.)

The plan adopted of covering the flanges of the steam pipes (page 557) appeared highly desirable, when it was remembered that each square foot of bare steam-pipe surface lost half a ton of coal per annum, if in constant use. Details of the method adopted of covering the flanges would be interesting.

It might be much doubted whether the use of a large number of small units of machinery, entailing so complex an arrangement of switchboard, was what would be generally recommended for a central station. The work of attention must be greatly increased thereby, as well as the cost of duplicating so many parts. When it was remembered that the low-tension supply and also the lighting of arc lamps, together with scattered suburban lighting, could all be carried out from one set of machinery on the alternating method, he could not see wherein lay the advantage of a combination of alternating and continuous-current dynamos together with motor rectifiers. If it could be shown that there was considerable saving in first cost, there would be some ground for such a plan; but as the first cost, instead of being less, was in reality greater, owing to the greatly increased quantity of copper required on the low-tension direct plan, he could not help thinking that a large city like Edinburgh should have commenced with fewer and larger units of machinery and on the alternating plan.

In the high-tension portion of the station it seemed to him unfortunate that the odd number of 52½ complete alternations per second had been adopted (page 565). The multiplicity of periodicities would seriously prevent manufacturers of electrical machinery from keeping in stock a supply of transformers and motors. It was most desirable that some arrangement should be come to, whereby the variety of periodicities adopted might be minimised. To bring this about would be useful work for the electrical section of the London Chamber of Commerce.

The difficulty of keeping the pressure constant, owing to the variation of the balancing from hour to hour, had been rightly referred to in page 568. It would be interesting to know whether in the course of a few years that difficulty would not be greatly increased in such a system of feeders as was used for Edinburgh.

It seemed to him doubtful whether the omnibus bars would then be of much service, except for light loads: unless indeed wasteful rheostats or similar resistances were inserted in each feeder, and the station voltage were increased above the average requirements.

In the junction-boxes of the distributing mains, Fig. 11, Plate 149, it seemed to him that the bending of so large a cable to so small a radius as was there shown must be apt to injure the insulation. Moreover the moisture condensing on the porcelain cap would keep dripping upon the portions of the insulation underneath; and it appeared to him that in course of time this drip would affect the insulation of the cables. Doubtless such a result would take some years to come about; but eventually he thought this would be found to be a weak point in the plan, as the rubber would not stand continual alternations of drying and wetting.

Mr. E. Tremlett Carter pointed out that the superheating or drying action advocated by Mr. Geipel (page 576) took place to some extent in engines governed by throttling, at low loads especially; and if, instead of generating the steam in the boiler at a higher pressure than the initial at full load, it were generated at the actual pressure required for full load, there would at light loads be a certain amount of drying action in an engine governed by throttling and not by variable cut-off. Moreover the drying action would be greater as the velocity of the steam in the pipes was lower, that is, when the load was lower, and when consequently the liability to condensation in the main range of steam pipe would be increased. In this way there was a little compensation, but he thought not much; at any rate not enough to compensate altogether for the condensation in the steam pipe. To generate steam at a much greater pressure than was absolutely required at full load, and then to throttle it down, in order to balance the condensation which would take place in the range of steam pipes, he should think would be a much more expensive way of getting rid of condensation than to use a superheater, especially if the superheater were placed sufficiently forward in the boiler flues to obtain the benefit of the heat first-hand instead of second-hand.

Mr. William H. Patchell mentioned, with reference to electrolytic action between the copper and steel in the steam pipes (page 577), that some time ago, when using copper jointing pieces for steel pipes with steel flanges, he had found they stood well with ordinary London hard water, and there was no trouble at all with them. But when water was used which boiled alkaline, such as the deep chalk water in London, they had given trouble after trouble, and he had had to take out the whole lot of the copper jointing pieces. Every one had become corroded at the bottom side of the pipe. This he attributed almost entirely to the alkali carried over by the steam from the boiler, which did not give particularly dry steam, and to the subsequent condensation in the pipe. The bulk of the damage was where it would be expected, namely in the bottom of the pipe; and that was where every one of the joint rings had failed. In using compound pipes therefore, of copper and steel, it was necessary to consider what class of water was being used, and how it was being evaporated.

Mr. Sydney W. Baynes, Electrical Engineer to the St. Pancras Vestry, thought there was not really much cause for alarm in regard to the bending of the cables in the junction-boxes (page 579); the radius did not look to him so small as to bring about any injury to the cables.

With regard to the question raised as to the necessity for employing rheostats on the feeders (page 579) as soon as they became loaded up, this theory would be found contrary to actual experience. In practice feeders supplying a network, if well proportioned, seldom varied relatively more than 2 per cent. in pressure. In the event of excessive variation, it would be simpler to amass those of known voltage on to a separate omnibus bar, fed by a dynamo at suitable pressure: so that the expensive rheostats suggested would not be found necessary. At Bradford the station had been started with expensive rheostats; and later on, as the mains were loaded to even 50 per cent. in excess, the rheostats were not required, as the load was found to have become fairly even. There was not a variation of more than $1\frac{1}{2}$ per cent. between any of the mains

throughout the town. He was himself inclined to adopt a higher voltage throughout, which would greatly modify any difference that there might be between the feeders, because a variation of 2 per cent. on the feeders when running at a high voltage would give a larger working range for actual fluctuation than at a lower pressure.

He asked what was the weight of water evaporated from and at 212° Fahr. per pound of coal consumed ; and also what was the rate of the evaporation at the time of making the tests; and the class and price of the coal.

Mr. E. R. Dolby asked whether any difficulty had been experienced from vibration in the suspended ring of steam pipes. Recently in a central station he had seen a ring main held up by being slung in the manner described in page 557, which he considered was by far the best way of hanging steam-pipes so as to allow for expansion; but in the particular station he had visited the suspended ring-main was in a vertical plane. The main was about 70 or 80 feet long, the circuit rectangular in shape, and the top and bottom pipes were about 6 feet apart. The top line of pipe was hung up by links to brackets, exactly as described, and the bottom line of pipe was hung up to the top pipe, so that the whole ring was hanging on slings from brackets. The pendulum motion in the ring main he was told was so excessive that brackets with rollers had had to be put under the lower part of the ring main. When the brackets with rollers were put under, the expansion did not take place so freely as before; and therefore the middle of the pipe had to be held fast from moving, and an expansion joint put in at each side. It was quite possible that where the ring main was in a horizontal plane there might be no such vibration, and he should be glad to know what experience there was on this point; but if the ring main was in a vertical plane he thought that might not be the best way of supporting it.

Mr. E. W. Monkhouse showed a diagram, Fig. 13, Plate 150, of the total units generated in the Edinburgh station, the total number of lamps lit, the maximum load, and the total cost per unit, for every

(Mr. E. W. Monkhouse.)
week from the beginning of the second week in which the work was started to the week ending 10th October. It would be seen that the work started with about 2,500 lamps, and had gone up to 34,000 lamps. The cost per unit to begin with was fairly uniform per week. It went up a little as the load went down in June. From 27th June until 4th July it went down suddenly. It then went up again a little, because of the increase in the staff; and since then it had continued to go down, and had now got down to 0·9 penny per unit generated. The lowest cost per unit generated, in any one week, had been 0·886 penny. The highest cost per unit generated had been in the eighth week, June 6–13, and was 1·78 penny. At that time naturally the machinery had not been running quite as smoothly as it did now, and there had been various little things to be done, and rather more money had had to be spent. The cost per unit generated at the terminals, for the week ending 10th October was as follows:—station salaries 0·127*d.*, wages 0·313*d.*, fuel 0·319*d.*, stores 0·026*d.*, water 0·034*d.*, and repairs and carbons for the 177 arc lamps 0·088*d.*; making altogether 0·907*d.* per unit generated. The efficiency of the station, that is, the ratio of the units sold to the units generated, was 88·4 per cent. The cost to consumers, or the cost of the units sold, was 1·09*d.*, which he thought was fairly low for a station only six months old.*

There were now in Edinburgh altogether 24½ miles of low-tension road work, of which about 22 miles were distributing mains and the remaining 2½ miles were feeders. There would be altogether about 8 miles of high-tension road work when the ring main was completed which was now being brought out to the Meadows on the south side of the city.

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* Since 10th October the cost per unit generated has fallen considerably, and for the week ending 28th November was as follows:—station salaries 0·078*d.*, wages 0·195*d.*, fuel 0·261*d.*, stores 0·019*d.*, water 0·020*d.*, and repairs and carbons for 184 arc lamps 0·054*d.*; making altogether 0·627*d.* per unit generated. The efficiency of the station, that is, the ratio of the units on circuit to the units generated, was 88·4 per cent. The cost to consumers or per unit sold was 0·764*d.*

With the suspended ring-main of steam pipes at the station he had observed no vibration, and had had no trouble from that cause with any of the joints; the only trouble with joints had been from other causes.

Mr. John G. Mair-Rumley, Member of Council, asked whether any trials had been made with the superheaters and without them, and whether any idea could yet be given as to the saving which had been effected by their use. The adoption of superheating was an exceedingly interesting question. Its advantage undoubtedly depended a great deal upon keeping the superheaters clean. One superheater which he had at work on the Schwoerer plan he had had a great deal of trouble in keeping clean, and practically no superheat could be got out of it; but after putting steam-pipes round about it and cleaning the spaces by means of steam-jets, the temperature of superheat had been brought up to 100° or 120° Fahr. at the superheater. It would be of interest if the author could give the temperature of the superheat that was obtained at the superheater, and also the temperature of the superheat at the engine stop-valve, in order that the loss between the two might be known.

With reference to steam-pumps, there was no doubt that a steam-pump badly used was highly wasteful. But having tested a small direct-acting pump both with and without superheating, he had found that exactly half the steam was saved by superheating. The worse the engine, the larger of course was the amount of saving obtained by using the superheater. If the exhaust steam from the steam-pumps was taken to heat the feed-water (page 555), the loss from the wasteful use of the steam by the pumps would not be large.

Professor T. Hudson Beare shared Mr. Mair-Rumley's desire for more information about the effect of the superheating, which had been rather discredited by Mr. Geipel (page 576) because of the probable low temperature of the gases by the time they reached the superheater; while it had also been found that sufficient superheating could not be obtained in some arrangements to be

(Professor T. Hudson Beare.)

perceptible at the engine stop-valve. From experiments which he had himself been making recently as to the effect produced on initial condensation in the cylinder by moisture already contained in the steam when it arrived at the engine, he felt sure that, if superheating were only sufficient to ensure getting dry steam into the engine, one great difficulty would be conquered. There was a marked difference between the amount of initial condensation when absolutely dry steam was admitted into the cylinder, even without any superheat and at only the natural temperature of the steam, and when steam was admitted which contained only a comparatively small amount of suspended moisture. Even if superheaters did nothing more than ensure really dry steam at the engine stop-valve, he felt sure they would have a large share in inducing economy in steam consumption. The loss in the steam-pipes, which might be termed, for want of a better expression, the loss between the boiler and the engine, was much greater than was generally believed. It had become so much the habit in recent years to measure the steam consumption by the amount of water which came out of the condenser and was drained off in the steam-jacket, that it was apt to be forgotten that a great deal more than this had to be put into the boiler. There were invisible leaks everywhere, and extensive condensation was induced in the large and long steam-pipes in all central stations. The introduction of superheating therefore in the Edinburgh station he considered ought to be welcomed, as likely to give figures which were everywhere badly wanted as to the value of superheating in eliminating these losses.

Mr. James Platt, Member of Council, considered that with the short dry-backed boilers described in the paper the superheaters ought to prove highly efficient; and that an economiser would also be of advantage. With such short powerful boilers the temperature of the gases in the chimney he thought would be so considerable that probably an economiser would pay. There was indeed a feed-heater, into which the exhaust steam from the steam-pump was delivered, and he thought a little more heat might still be got from the flue with such short boilers. In Lancashire it was thought that there

was nothing like a good long boiler, and that there was some heat wasted in the flues of shorter boilers; it was better therefore to recover some of this waste by an economiser.

Mr. Edward B. Ellington mentioned that he had lately been making some experiments as to the quantity of coal required to keep up the steam in boilers when no work was being done at the several hydraulic-power stations in London; and he had been much surprised to find the great discrepancy that existed in the different classes of boilers. In two Lancashire boilers for instance, he had found that, when there was no work doing and the engine was not running, 14 cwts. of coal was consumed in twelve hours, including the waste of heat in the steam-jackets and economiser. In two Fairbairn-Beeley boilers, described at the last meeting (page 356), which were working under similar conditions, the amount of coal consumed in twelve hours was only 8 cwts., as against 14 cwts. in the Lancashire boilers. Both the Lancashire and the Fairbairn-Beeley boilers evaporated about 4,000 pounds of water per boiler per hour. Such a consumption of coal with the engines standing amounted to a large loss in the course of the year; and he considered the principal reason of the difference between the two kinds of boilers was simply the larger amount of surface from which heat was lost in the Lancashire boilers, though at the hydraulic station where only 8 cwts. was used in twelve hours the flanges of the jacket steam-pipes were covered, and the dampers were so arranged as more effectually to prevent the admission of air when closed. If the information was available, he should like to know what amount of coal was consumed in one of the Edinburgh boilers simply to keep the steam up, without using it for work at all.

As to vibration of the steam-pipes (page 577), he had used ring steam-pipes in a similar way to that shown in the drawings, and had met with no trouble at all from vibration. There were no copper bends; they were all of steel. It had been found necessary to allow for a certain amount of vertical movement in the pipes, and this had been done by supporting on springs the rods carrying the pipes. There had been some trouble when there was a rigid connection vertically.

(Mr. Edward B. Ellington.)

He was glad to see superheating employed at the Edinburgh station, for he thought there must be a great deal of economy to be derived from it, even should the cost of maintenance of the superheater be considerable.

Mr. William Geipel considered the particulars given by Mr. Monkhouse (page 582) respecting the working of the station in Edinburgh were most interesting; he thought they were about the best he remembered having ever heard. The cost of working a station however was only the smaller part of the total cost of the supply to the consumer. The greater part of the cost was made up of depreciation and standing charges; and it was for this reason chiefly that he had suggested the use of a smaller number of larger units. If the first cost of this station when all the distributing mains were being fully drawn upon could be brought down to anything like the cost of an alternating station, then the figures as to working cost, given by Mr. Monkhouse, came remarkably close to some which he had himself given, in the discussion upon the paper read by Mr. Crompton to the Institution of Electrical Engineers * about a year ago, as to the ideal cost of working a central station. In that estimate he had calculated the lowest cost of working a station per unit

* Institution of Electrical Engineers, 1894, vol. 23, page 480. The two estimates of working cost compare as follows with the actual cost given by Mr. Monkhouse (page 582):—

	Crompton. Ideal cost.	Geipel. Ideal cost.	Edinburgh. Actual cost.
Station salaries	0·10*d.*	0·20*d.*	0·127*d.*
Wages	0·10	0·20	0·313
Fuel	0·27	0·15	0·319
Stores	0·02	0·04	0·026
Water	0·01	0·01	0·034
Cost per unit generated	0·50	0·60	0·819
Repairs and Carbons	..	..	0·088
Maintenance 2 per cent.	0·40	0·22	
Management	0·42	0·42	
Profit 7 per cent.	1·68	0·76	
Sale price per unit, pence	3·00	2·00	

generated to be 0·6*d.* excluding carbons; while in practical work Mr. Monkhouse had got down to 0·9*d.* including carbons. Water he noticed came to 0·034*d.* per unit; if condensing had been used, it would probably have been only a tenth of 0·034*d.*; since it was as much as 3 per cent. of the total cost, it was deserving of consideration, when strenuous endeavour was being made to reduce the cost by every fraction of a penny.

Mr. C. Frewen Jenkin asked how the steam-pipes were connected to the engines. The main problem in allowing for the expansion of the steam-pipe, he thought, was how to allow the pipe itself to expand, and yet to make a connection from it to the fixed engine. Having arranged steam-pipes along brackets, he had found that the connecting pipes to the fixed engines unscrewed and worked loose in their flanges, owing to the forward and backward motion of the main steam-pipe in expanding and contracting. He should like to know whether in the Edinburgh station the main steam-pipe was always kept full of steam; or whether it was allowed to get cold during the day, when the load was taken by the batteries. If the latter, it seemed to him that, when more engines were put in, it must lead to trouble; for the long range of steam-pipe would expand, as far as he could make out, about 3 inches between hot and cold.

Mr. Druitt Halpin had lately seen at Aix-la-Chapelle an arrangement on a large scale for transforming a continuous current into an alternating. There were three engines of 350 H.P. each, for generating a continuous current at a pressure of 210 volts for the electric lighting; and a highly favourable bargain for the station had lately been made with the authorities to drive the tramways, extending about 40 miles through the town. For this purpose two triple-expansion engines only were added, of 150 H.P. each, without any reserve at all. These two engines were kept running all the time at full load; and when more power was wanted, the continuous current was taken from the other engines, or from their batteries which were large, and was employed to

(Mr. Druitt Halpin.)
drive motor transformers; and by that means the expenses of stand-by engines were saved.

He could not follow the argument (page 584) that, because the Edinburgh boilers were so short, they afforded a good opportunity for the adoption of an economiser. It was surely a question simply of the amount of heating surface presented to the products of combustion, quite apart from the length of the boilers. With regard to the experiments (page 585) on the radiation from boilers—equivalent to 8 cwts. of coal in twelve hours in one instance, and 14 cwts. in another—this was highly valuable information; but there was also another factor, which he thought ought certainly not to be overlooked. In experiments carefully made by a commission* in Frankfort in 1891 great stress had been laid, and perhaps rightly, not only on the radiation, but also on the leakage of air into the boiler flues through the brickwork. By those experiments it had been demonstrated that the final efficiency of the boiler, that is, the evaporation divided by the thermal units in the coal, ran out practically in an absolutely fair curve, according to the excess of air which leaked through beyond the quantity theoretically required for combustion. The leakage of air was determined in three ways. Firstly the theoretical amount of air was determined; then the amount of air immediately behind the bridge was determined, which showed the excess coming through the furnace; and finally it was further determined at the entrance to the chimney what an enormous leakage there had been through the brickwork. If regard were paid to the condition of the brickwork and to the extent of radiation, he thought much light would be thrown upon the subject, because the extent of radiation from the boiler itself must be exceedingly small, inasmuch as there was so little of the boiler surface that was available for radiating, namely the top and front only; in the present instance also the top surface of the boiler was covered by the superheater.

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* Bericht über die Arbeiten der Prüfungs-Kommission; published by J. D. Sauerländer, Frankfort-on-Main, 1894.

Mr. Horace Wm. Wright noticed that it appeared from the drawing, Fig. 3, Plate 142, that no provision had been made for cleaning out the feed-heater, in which of course sediment would gradually collect in consequence of the heating of the feed-water therein. Whenever it became necessary to take the casing off for cleaning out the interior, he feared a good deal of expense would have to be incurred in lifting it. If proper provision for cleaning had been made when the heater was erected, much expense he considered would have been saved, which would eventually affect the economy of the station.

Mr. E. W. Monkhouse said that in summer, when the station stopped working tolerably early in the light mornings, the engines did not start until nine o'clock at night; and it took 3 cwts. of coal per boiler to keep the steam up during the day, doing nothing but banking the fires.

With regard to condensation of moisture on the Doulton-ware caps in the junction-boxes (page 579), there were several boxes in Edinburgh which were particularly wet, as he supposed had always been found to be equally the case elsewhere; but he had found that no water at all got underneath the caps; on lifting the caps he had found they were perfectly dry underneath. It would be noticed that the caps were made of such a depth that any water dripping from them could drip only upon the cable itself; but the quantity of water so dripping from the caps he had found was not great at present, and the dripping had not yet continued long enough for him to find out that the rubber would not stand continual alternations of drying and wetting; and he hoped he should not find this to be the case after longer experience.

Mr. Sydney W. Baynes suggested that all risk of injury to the insulating covering of the cables might perhaps be obviated by giving the edge of the caps a slope, so that the moisture could drain off them at one point, and drip clear of the cables.

Mr. Burstall replied that the reason why continuous-current transformers were not used (page 574) was largely because of the nature of the district to be served, in which it was possible that for many years to come the lighting would be sparsely scattered; and therefore isolated transformers would have to be used. With continuous-current transformers, low-tension mains would be required.

Respecting the cost of driving the electrical pumps (page 575), no information he believed was at present forthcoming. Although it was known how many units they took during the week, he believed the horse-power they had developed had not yet been determined. Naturally in the first six months of the working of a new station the engineer had little time for testing, having to concentrate his attention upon the successful working of the station.

The superheaters (page 575) had been in use from the first start, and no trials had yet been made without them.

In reference to the remarks (page 578) as to the advantages of high tension over low, it was easy to make plausible statements as to the economy in mains which must result from using a small current at high tension to transmit the same energy as a large current at low tension; but in such statements the fact was lost sight of, that in all modern high-tension systems, whether alternating or direct current was used, the current was distributed by low-tension distributing mains, except in just such districts as were being supplied by high tension in Edinburgh, that is, where the houses were scattered. Thus the only saving to be obtained in mains by using a high-tension system was in the feeders, the distributing mains on both systems being the same size. The capital cost of the heavy feeders on the low-tension system, which might, as in Edinburgh, be laid in a cheap form, had to be compared with the capital cost of the smaller but more highly insulated feeders, together with the cost of the transformer sub-stations, the transformers, and their switching gear. It would thus be seen that, as far as capital cost went, no one system could be said offhand to be better than any other for every town or district, but that every place had to be treated on its own merits. For Edinburgh six systems at least had

been considered and worked out, each with equal care, before the particular system finally adopted was chosen as best fitting the circumstances.

As to the use of steel flanges on copper pipes (page 577), he had as yet had only six years' experience of them, and during this time had had no trouble with them.

With regard to vibration of the ring main of steam-pipes (page 577), he had had experience with several ring-mains constructed in identically the same way, and suspended in the same way, and little or no trouble had been met with from vibration. Although the ring main was slung on rods, or supported on roller brackets in some cases, it was held at a good many points, though not rigidly. In Edinburgh there were connections to eight engines, and two connections to the boiler-house main. Steam was not kept continuously in the pipes (page 587), but no trouble had yet been found from expansion and contraction of the pipes, either in Edinburgh or in other stations where similar rings had been used; the ring being held lightly at several points did not move bodily. He had himself seen a ring of steam-pipes which moved between two and three inches when the steam was first turned on; and that steam ring was running perfectly well now. No trouble had been found from the connections between the ring mains and the engines; in the Glasgow central station eleven engines had now been connected; the ring main was there held at a great many points, and as far as he knew no trouble had been experienced.

Provision had been made by means of doors at the side for cleaning out the feed-heater (page 589); and since it had been erected it had already been cleaned out. The cost of cleaning had been so small that he thought it had not affected the station costs.

If the station cost in Edinburgh was approaching pretty closely to the theoretical best (page 586), at any rate the figures given by Mr. Monkhouse were not the only ones, for he knew of another station, with an output of less than 4,000 units a week, at which the total works costs amounted to $0 \cdot 9d.$ per unit generated: so that, if this result was near the theoretically possible, it was also practically possible.

The President said that the matter of superheating was of course one of general engineering interest. The superheating arrangements in Edinburgh were not by any means finished, although the superheaters had been in use from the commencement. At first they had been so arranged as to have an undesirable tendency to superheat other things besides the steam; but this was being remedied, although even yet the superheating was not sufficiently complete. On 20th September, after he had had two or three days' working of the boilers, the actual evaporation per hour during a run of six hours was 8,130 lbs. in one boiler at an average pressure of 142 lbs. per square inch. The superheat however appeared to be only about 10° Fahr. at the boiler, and there was no superheat at all at the engines. In the length of the superheater itself there was a drop of temperature from 738° to 584°, that is, the gases had lost 154° in passing through the superheater. The corresponding amount of heat was more than enough to superheat all the steam; unfortunately it did not yet appear to be sufficiently utilized. With the temperature of 738° in the smoke-box end of the superheater, and 584° in the back end, the temperature in the flue underneath the boiler, just going into the main flue, was 552°. On another day and with another boiler he had obtained results which did not differ much from these. The evaporation under these circumstances was remarkably good. The actual evaporation of water per pound of dry coal was 9·1 lbs.; or reduced to standard evaporation from and at 212°, 9·55 lbs. The small coal used cost 7*s.* per ton; and the above evaporation was 73·4 per cent. of the theoretical or calorimetric value of the coal. As was well known, it was not easy to get so good an evaporation as this with small coal and with mechanical stoking. The rate of combustion was high, amounting to 55·8 lbs. of coal per square foot of grate surface per hour. (This was calculated on the actual moving grate-bar surface of 16 square feet per boiler. With Sinclair's grates there was in addition a large dead-plate, and also a certain space at the back end of the bars, on both of which no doubt combustion did actually go on.) The average amount of carbonic acid in the furnace gases was 9·3 per cent. by volume. In a trial made on the previous day there had been only 5·7 per cent.

of carbonic acid with a combustion of only 45 lbs. of coal per square foot of grate per hour, and a boiler efficiency of only 69 per cent. By taking such steps as were indicated by these results, the higher figures already given were reached on the following day. From the superheaters he hoped to get good results, though naturally not so high as would have been obtained if he had gone to the extreme of putting the superheaters in a much hotter part of the furnaces. No doubt that would have been better for the sake of getting the heat; but he had felt a little hesitation about doing this, because the superheaters would then have been too much out of reach; in their present position on the top of the boilers the whole of the apparatus was entirely within reach. Any further results obtained in the course of the coming winter he would take care should certainly be published in some form, so that everybody could see them; because it was a matter in which engineers were all interested.*

The waste of heat by radiation (page 578) was also a subject in which engineers were much interested; and they would lay to heart Mr. Geipel's statement that one square foot of bare steam-pipe surface radiated heat which was equivalent to half a ton of coal per annum, provided it was always in use. In an earlier stage of the Edinburgh station he had happened to meet with an interesting physical illustration, by which the radiation from the steam-pipe flanges could be shown. The pipes themselves had all been covered already, while their flanges had not yet been covered; there were arc lights in the station, and the shadows of the pipes and flanges were thrown on the wall. The shadows of the pipes were marked by perfectly quiet lines; but the shadows of the flanges were in a state of violent ebullition, which could be seen streaming upwards through a height of three or four feet. Obviously the air was set in rapid motion by the heat radiating from the flanges.

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* Since the date of the discussion many other experiments have been made, and at the end of 1895 the amount of superheat in the steam in regular work is as much as 60° Fahr., and often reaches 80° Fahr., which appears a highly satisfactory result.

(The President.)

The capital costs (page 576) had not been given in the paper, but no doubt the author would add them. All the capital costs at the various electrical stations were of course published annually, and thus became public property. On looking at the capital costs of the various stations working on the various systems, he thought it would be found that there was not the least foundation for Mr. Geipel's suggestion (page 578) that high-tension work cost less per kilo-watt than low-tension; and he was rather surprised that this old fallacy should be brought up again, especially when it was so easy for everyone to see for himself what the actual facts were.

In regard to the suggestion (page 578) that larger units should be used, the primary object of all electrical stations was to run steadily and easily, and to make money. It had been found in many cases that running was neither so easy nor so profitable where the size of the units had been large. It seemed to be sometimes forgotten that even in the largest station there were hours when hardly so much as 100 H.P. was wanted. Moreover variation of load occurred not only every day, but to a still greater degree at different times of the year. In his own experience he had found that, even in large stations, the advantage of having small units was very great, always supposing the small units to be so arranged that they could be started and stopped with great convenience, and could be put into combination in any way required. It was no doubt a matter of opinion; but this was his own deliberate opinion after considerable experience in connection with various kinds of electrical work.

The author of the paper, though he had said so little about his own connection with this work, had in reality had a great deal to do with it from the commencement; and he was therefore specially glad that Mr. Burstall had been able to prepare the paper. It should also be mentioned that Mr. Monkhouse, who had come from Edinburgh expressly in order to attend the present discussion, was responsible for putting the whole station together, and more especially for carrying out the 24 miles of road work which had been completed before the station was opened. That work had been all carried out by himself and his own men, and at a cost which was remarkably reasonable, at any rate much lower than the lowest

cost at which it would have been carried out otherwise. The work had turned out most satisfactorily; and he was glad to be able to congratulate Mr. Monkhouse not only on having carried it out in that way, but also on the really excellent figures which he had been able to present as the results of only six months' work under his charge. He now asked the Members to pass a vote of thanks to Mr. Burstall for his paper.

Mr. C. S. Vesey Brown, Borough Electrical Engineer of Sunderland, wrote that the town of Sunderland is similar to the city of Edinburgh in one respect, namely that the older and business part of the town is compact, and the residential district scattered. The systems of distribution adopted are similar to those in Edinburgh, namely low-tension three-wire for the business part of the town, and alternating high-tension for the suburbs. The adoption of these two systems combined is due to Professor Kennedy; and Sunderland was the first place, the writer believes, in which it was proposed to use the combination. There are three Lancashire boilers, 7½ feet diameter by 28 feet long, with additional steam-drums, made by Messrs. Hawksley, Wild and Co., of Sheffield, supplying steam for five sets of Willans engines and Holmes dynamos, three of which indicate 80 H.P. and the two others 40 H.P. each; these constitute the low-tension portion of the machinery. The high-tension portion consists at present of two sets of Crompton alternators, each of 38 kilowatts, driven by continuous-current motors There is also a set of Electric Power Storage accumulators, which enable the station to be supplied during the hours of light load with the boilers shut off. With the exception of the motor alternators, the station has much that is similar to an ordinary low-tension station. The ingenious arrangements of the battery-regulation and hospital-cell switchboards, used in Edinburgh, are in use here also, and are found to be all that can be desired; and though at first sight the switchboards appear complicated, yet the attendants have had no difficulty in learning and using the different connections on these boards; the chief usefulness of the hospital-cell switchboards

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(Mr. C. S. Vesey Brown.)
lies in the fact that the regulation can be effected on them without interfering with the main-battery switch. In the low-tension feeders there is about a quarter of a mile of copper strip, the rest being armoured rubber cable; and the network of mains is composed entirely of rubber cable, drawn into Doulton stone-ware casing under the footpath, and into cast-iron pipes under the roadway. The Doulton casing has proved a great success; it is about half the cost of cast-iron pipes equal in number to the ducts in the casing, and it is quickly laid; the only drawback is the difficulty at present of making it in longer lengths than three feet. The high-tension mains are of the British Insulated Wire Co.'s make, and are laid in the same manner as the low-tension mains, with the exception that where practicable stone-ware boxes have been used instead of brick boxes, the former being more quickly placed in position and less liable to leakage of water. Transformers are buried in the streets under the footpath, and are provided with high-tension switch and fuse; each transformer supplies its own little network at present, but eventually these smaller networks will be joined up, so as to supply all together and thereby equalize the pressure better.

Mr. Burstall wrote that the capital expenditure on the work described in the paper has been as follows:—

Land and preliminary expenses	£14,300
Buildings	18,000
Machinery and plant in station, arc-lamps, and lamp-posts .	34,600
Mains and roadwork	48,800
Total . .	£115,700

These figures are the actual sums expended, to the nearest £100. It will be seen from them, and from the capacity of the plant in the station, that the capital cost per indicated horse-power installed is £63·6, and per kilo-watt installed £91·1. A comparison of these figures with the published capital costs of other installations in this country shows that, while the costs per kilo-watt installed in Edinburgh are slightly higher than the average of municipal installations of the same capacity, they are well below the average of

the various companies. It is of interest to note that these published figures in no way bear out the statements sometimes made that the high-tension system is always cheaper than the low-tension; on the contrary, the average cost per kilo-watt installed is sensibly the same for installations on both systems.

An important point however in the design of the Edinburgh installation has been the provision in the first capital expenditure for future extensions; and this has made the capital cost for the first instalment of plant seem higher than it really is. Extensions, which will nearly double the capacity of the station and mains, are now being proceeded with; and the cost of these extensions will not exceed £30,000, which will make a total capital cost of about £146,000. The capital cost per kilo-watt installed will be brought to about £58, which is much lower than the average for even municipal installations.

In regard to the actual total cost of the feeders, he had found that, owing to the fact that the feeders in many places were laid at the same time as the distributing mains, it was difficult to separate the sums paid in roadwork and jointing for the two together. The cost of armoured cable and copper strip for the feeders was in round figures £8,500, or only about 7·4 per cent. of the total cost; and any saving to be obtained by using high tension could be made only on this amount. The cost of a system of high-tension feeders with their transformers, sub-stations &c., would have been closely the same as that paid for the low-tension feeders; but the roadwork would have been somewhat less for the former, because plain trenches would have been used instead of culverts in a good many places. If the capitalised value of the rent of sub-stations and of the wages of men for switching the transformers on and off were added to the other costs, the high-tension feeders would have actually cost more than the low-tension. This would be entirely different if the site of the central station had been far away from the centre of the city, and if the feeders had had to be made considerably longer.

As to the efficiency of the motor-driven pumps (page 574), subsequently to the discussion on the paper Mr. Monkhouse had made a test of the pumps, and had found that, with the pumps

(Mr. Burstall.)
running at one-third of full load, the combined efficiency of the motor and pump was about 49 per cent., 2·66 units being used per thousand gallons pumped against 150 lbs. pressure per square inch.

He was sorry that, through his fault, a misunderstanding had arisen as to the periodicity at which the alternators would be worked. The figure given in the paper, 52½ complete alternations per second (page 565), was the periodicity attained when the engines at present in the station were run at their nominal full speed; but as soon as any additional plant was put into the high-tension section, the present engines would be run slightly below their full speed, and the whole of the alternators would run at a periodicity of 50 complete alternations per second, which was the specified periodicity, and that for which all the instruments, transformers &c., were designed. He doubted however whether such an alteration made any real difference in the design of transformers.

REPORT ON THE LILLE EXPERIMENTS UPON THE COMPARATIVE EFFICIENCY OF ROPES AND BELTS FOR THE TRANSMISSION OF POWER.

Translated by Professor DAVID S. CAPPER.

The idea of making comparative trials of the work absorbed by Ropes and Belts in the Transmission of Power was first suggested to the civil engineering committee of the Société Industrielle du Nord de la France, in connection with a paper by M. V. Dubreuil, read and discussed at their meetings on 25th May and 25th June 1893. For preparing his paper M. Dubreuil wrote to a large number of manufacturers both in France and in other countries, asking their opinion on this subject. The replies he received were uncertain and contradictory, and brought to light a general desire for the matter to be investigated. With this object M. A. Dujardin, a Lille engineer, offered to furnish at his own expense a 200-H.P. steam engine, fitted with both rope and belt fly-wheels of $14\frac{3}{4}$ feet ($4\frac{1}{2}$ metres) diameter,* on which exhaustive experiments could be made. The committee accepted the offer, and appointed a commission of five, afterwards increased to nine, with power to invite the co-operation of those who, though not belonging to the Société Industrielle, were interested in the question. This appeal was successful, and on 5th November 1893 six additional members were elected by a general meeting to represent on the commission those who had responded to the invitation. Thus completed, the commission consisted of the following fifteen members:—Messrs. Bonet, chief engineer of the Steam Boiler Association of the North of France; D. S. Capper,

* This diameter was afterwards altered to the diameters given in Tables 1 and 13. [Translator's note.]

professor of mechanical engineering, King's College, London; Chapuy, engineer, Corps des Mines, Lille; de Cuyper, engineer, managing director of the works of Van den Kerkove, Ghent; V. Dubreuil, engineer and architect, Roubaix, delegate of the Société des Ingénieurs Civils, and of the Association des anciens Elèves de l'Ecole nationale des Arts et Métiers, President of the civil engineering committee and of the commission for the rope and belt trials; A. Dujardin, manufacturing engineer, Lille; Goerich, manager of the Alsatian Engineering Works at Mulhouse and Belfort; Gruson, engineer-in-chief, Corps des Ponts et Chaussées, director of the Industrial Institute of Lille; Colonel Laussedat, director of the Conservatoire des Arts et Métiers, Paris; Olry, engineer-in-chief, Corps des Mines, general delegate of the Council of the Steam Boiler Association of the North of France; Neu, electrical engineer, former pupil of the Polytechnic School, professor at the Industrial Institute of Lille, co-delegate of the Société des Ingénieurs Civils; Schmidt, engineer-in-chief of the Steam Boiler Association of the Somme; Vigneron, mechanical engineer, manager of the cotton mills of Messrs. Wallaert Brothers, Lille; Villain, manufacturing engineer, Lille; Witz, mechanical engineer, doctor of science, professor at the Free Faculty of Science, Lille.

A meeting of the commission was held on 5th February 1894, when the following resolution was passed:—

Firstly, the steam engine shall have a double fly-wheel or two fly-wheels, one for the belt and the other for the ropes.

Secondly, the dynamo, driven direct off the fly-wheel without a counter shaft, shall likewise be provided with two pulleys, one for the belt and the other for the ropes.

Thirdly, the dynamo shall be mounted on adjusting screws, so that the tension of the belt or ropes can be regulated at will.

Fourthly, a cotton belt is to be ordered from M. Lechat of Ghent and Lille; a leather belt from M. Lemaire of Tourcoing; a homogeneous leather belt from M. Domange of Paris; and ropes from Messrs. Saint Brothers of Paris.

The experiments shall be made alternately with ropes and belts, several tests being made each day. The trials being comparative,

and the double fly-wheel allowing alternate runs with ropes and belts, it may be assumed that the mechanical efficiencies of the engine and dynamo will not vary during the experiments, and that it will consequently not be necessary to determine these.

For carrying out this programme M. Dubreuil was assisted by those members of the commission who had had experience in experimental work and were willing to make the observations; and also by those who were willing to lend apparatus at the least cost, so as to reduce to the lowest possible the expenditure on machinery, which would otherwise have cost £6,000 (150,000 francs). The experimental staff consisted of the following experienced observers:— M. Bonet, chief engineer, aided by the staff of the Steam Boiler Association; Messrs. Neu and Paillot, professors at the Industrial Institute and the Faculty of Science at Lille; Messrs. de Loriol, Finet, and Maréchal, electrical engineers representing the Alsatian Company; and M. A. Dujardin, manufacturing engineer, Lille. The Alsatian Company furnished and laid down and took charge of a 200-H.P. dynamo constructed especially for these trials. Messrs. Gabriel and Anguenault of Paris supplied 1,800 incandescent lamps. M. Henneton of Lille fitted up 300 additional lamps. The Industrial Telephone Company of Paris supplied the electric leads, and Messrs. Lazare Weiller and Co. of Paris the main copper conductors. Messrs. Sage and Grillet of Paris sent lamp-frames and accessories. Messrs. de Loriol and Finet supervised the general fitting of all the electrical apparatus. Messrs. Lechat, Lemaire, Domange, and Saint Brothers, supplied the belts and ropes. The Northern Railway lent one of their powerful boilers. Messrs. Dujardin and Co. not only provided the engine, the steam supply, and a site suitable for the erection of the machinery, but also defrayed a number of incidental expenses. To the gratuitous help thus given the success of the experiments must be largely ascribed.

Method of carrying out the Experiments.—In carrying out the experiments it was assumed that, given a constant resistance, and power applied in overcoming it, any variations in the power will be due to the particular efficiency of the transmitting medium—ropes

or belts—which alone can modify the result. In conformity with this principle, the resistance was provided by a sufficient number of incandescent lamps to maintain the output in watts constant; while the revolutions of the engine and dynamo were recorded, the speed of the latter being kept constant throughout the whole of the trials, and indicator diagrams were taken at the exact moment when the load was normal.

Constancy of Load.—As constancy of load was of the utmost importance, special care was taken throughout the whole duration of the experiments that the difference of potential at the terminals of the lamp circuit, and the current through the lamps, should be constant: in other words, that the number of watts absorbed by the lamps should be the same in every case. The difference of potential and the current were measured in M. Dujardin's office, at such a distance from the dynamo and lamps that all disturbing influences were almost entirely got rid of. The instruments were lent from the physical laboratories of the Faculty of Science and of the Industrial Institute.

Difference of Potential.—To measure this a torsion voltmeter by Siemens and Halske was used; it was carefully calibrated, and could be read with ease to one-third or one-fourth of a volt.

Current.—The determination of the current in ampères would have presented greater difficulty; but as it was not necessary to know its exact value, but only to ensure that it should be constant, the following method was adopted. At two points on the main circuit, about a yard apart, two fine leads were attached, and led to the terminals of a highly sensitive Wiedemann and d'Arsonval galvanometer. The readings were taken by Poggendorf's reflecting method, which proved too sensitive. It was therefore found necessary to reduce the sensitiveness of the galvanometer, in order to keep the image upon the scale. The current, and with it the direction in which the spot of light moved along the scale, could be reversed by a commutator, so as to correct any possible variations of the zero point owing to alteration of the magnetic field. The difference between the two readings on the opposite sides of the zero point would remain constant for a constant

current. The recorded measurements were not commenced until a sufficient time had elapsed for the temperature of the conductor to become steady. The difference of potential and also the current intensity were measured every ten minutes. Any variation in the potential was corrected by altering the main stop-valve of the engine, and thus changing the speed; and a final adjustment was obtained by regulating the field. If, when the potential had been brought back to its normal value, a variation of current was observed, lamps were switched on or off until equilibrium was restored. Indicator diagrams were then taken. It was thus ensured that during the whole duration of the trials the lamps absorbed always the same number of watts.

Date of Trials.—The experiments were carried out on the 7th, 8th, and 9th of August 1894; and not only the members of the commission, but all who desired to attend, were admitted to them. On 9th August the commission met again, and drew up the following record.

Tuesday 7th August.—The morning was spent in preliminary trials for accustoming the observers to their duties, so as to avoid all risk of hitch in the subsequent runs. The newness of the machinery would probably have led to inconsistencies, if the experiments had been run without previous trial. During these preliminary trials it was found that the electrical instruments, which had been placed in an erecting shop, were affected by the shifting of iron forgings in their vicinity; and it was found necessary to remove them into M. Dujardin's office.

The observers were stationed as follows. The boiler was fired by a stoker of the Northern Railway, who received orders to keep the pressure constant at 96 lbs. per square inch ($6\frac{3}{4}$ kgs.). The steam engine was in charge of the engineers to the Steam Boiler Association, who also took the indicator diagrams, under the direction of M. Bonet. Messrs. de Loriol, Finet, and Maréchal took charge of the dynamo. The engine and dynamo counters were observed by the engineers to the Boiler Association and M. Dujardin. The lamps were superintended by the Alsatian Company, and the electrical

measuring instruments by Messrs. Neu and Paillot. The whole of the observations were under the general supervision of M. Dubreuil.

With a view to uniformity the procedure on all the trials was as follows. (1) A thirty minutes' run without load. (2) Another thirty minutes' preliminary run under full load. (3) Ten minutes allowed for final adjustments. (4) The actual trial, lasting 140 minutes, with fifteen sets of indicator diagrams taken at intervals of ten minutes. (5) Indicator diagrams taken after the load had been removed. (6) The driving ropes or belt taken off and weighed.

Trial 1.—In the afternoon of Tuesday, trial 1 was made with ropes. No account was taken of the first portion of the run, when the voltage* rose to 104. The trial was resumed at 94 volts. The trial began at 3.40 and ended at 6.0 p.m. During its progress the engine counter missed several times. During the run Messrs. Neu and Paillot found the voltage quite steady.

Trials 2 *and* 3, *Wednesday* 8*th August*.—In the morning, trial 2 was made with M. Lechat's cotton belt: the start was at 7.50; full load was put on at 8.20; and the duration of the trial was from 9.10 to 11.30 a.m. In the afternoon, trial 3 was made with M. Lemaire's leather belt: starting at 3.10, full load was put on at 3.40; and the trial was from 4.30 to 6.50 p.m.

Trials 4 *and* 5, *Thursday* 9*th August*.—In the morning, trial 4 was made with M. Domange's leather belt: starting at 7.50, full load was put on at 8.20; and the trial lasted from 9.10 to 11.30 a.m. In the afternoon, trial 5 was made with ropes, starting at 2.0; full load was put on at 2.30, and the trial lasted from 3.8 to 5.30 p.m.; the voltage was as steady during this trial as during the first rope trial.

After the trials a meeting of the commission was held on Thursday afternoon 9th August, M. Dubreuil, President, in the chair. Present: Messrs. Dujardin, Chapuy, Neu, Vigneron, Villain, Bonet, Capper, de Loriol, and Finet, as members of the commission;

* Although the potential difference is stated as "voltage," it was really measured in arbitrary units, whose exact relation to the volt was not determined and was unnecessary for the purpose in view. [Translator's note.]

Messrs. Lemarchand, delegate of the Industrial Society of Rouen, Paillot, and Dubrule, by invitation; and M. Letombe, assistant secretary. The president communicated the foregoing account of the arrangements that had been carried out during the three days' trial, which received the approval of the members present. At the request of M. Dubreuil, M. Bonet on behalf of the Boiler Association undertook to work out the indicator diagrams, and report the results to the commission in tabular form and in the order of the experiments. The president invited all the observers to report the observations on which they had been engaged; and asked Messrs. Lemarchand and Capper also to communicate their opinions.

Results.—In accordance with the request of the commission, the Boiler Association has worked out the indicator diagrams, of which a set of four was taken every ten minutes; and has prepared the accompanying detailed Tables 1–12, pages 608–619. A general summary is given in Table 13, page 620, from which the ultimate results can be gathered at a glance.

Summary.—Neglecting the first trial, which was rendered untrustworthy through the failure of the engine counter and the newness of all the apparatus, Table 13 shows that, with a constant resistance, the power expended in the several modes of transmission was as follows:—

Ropes,	gross power	158·54 I.H.P.	with a slip of 0·33 per cent.
Cotton Belt	(Lechat)	159·67 I.H.P.	„ „ „ 0·78 per cent.
Leather Belt	(Lemaire)	158·84 I.H.P.	„ „ „ 0·96 per cent.
„ „	(Domange)	160·23 I.H.P.	„ „ „ 0·78 per cent.

The diameters of the pulleys were measured at the surface and line of contact. Stated in percentage value, and allowing for the variations in the mean load as given in line 18 of Table 13, the results were as follows:—

Ropes,	gross power	100·00	. slip 0·100
Cotton Belt (Lechat)	„ „	100·87	. „ 0·237
Leather Belt (Lemaire)	„ „	100·37	. „ 0·292
„ „ (Domange)	„ „	101·07	. „ 0·237

General Remarks.– During the trials with ropes the tension gear was not used; but it was employed more or less throughout the belt trials, under the control of the belt makers, who regulated it as they pleased while running. Table 13, page 620, shows that the linear speed of the belts and ropes and their tension per square inch of cross section were very nearly the same. Thus the linear speeds at the surface of contact with the pulley, and the corresponding tensions, were as follows:—

Ropes	ran at 66·9 ft. per sec.	under	156·4 lbs. per sq. in.
Cotton Belt (Lechat)	67·2 ,, ,, ,,	,,	177·3 ,, ,, ,,
Leather Belt (Lemaire)	67·1 ,, ,, ,,	,,	134·4 ,, ,, ,,
,, ,, (Domange)	67·3 ,, ,, ,,	,,	156·1 ,, ,, ,,

The needle of the volt-meter was practically steady with the ropes, while with the belts it oscillated through one or two divisions. Though sufficient at times to render the reading difficult, the oscillation did not cause any fluctuation in the light. As it coincided exactly with the passage of the belt joint over the pulley, it proves the importance of making good joints. Owing to the necessity of limiting the number of experiments, the commission were unable to try all the forms of belt offered to them. They therefore limited themselves to those which have been in practical use for at least fifteen to twenty years. They regret however that M. Domange was accidentally prevented from sending for trial the "homogeneous belt" which was at first offered by his representative. The rim of the belt fly-wheel was made of Messrs. Van den Kerkove's form, for a belt of $17\frac{3}{4}$ inches width, as shown in Fig. 4, Plate 151. The rim of the grooved fly-wheel was made according to the plan usually adopted by Messrs. V. Dubreuil and A. Dujardin for rope gearing; it was grooved for five ropes of $1\frac{3}{4}$ inch diameter, as shown in Fig. 1. These drawings give all the necessary details, and Fig. 3 shows the method adopted for determining the depth of the ropes in the grooves and the diameter of the circle of contact, after the trials and before the ropes were removed. No mishap of any sort occurred during any of the trials. The dynamo, although

new from the manufactory at Belfort, ran without trouble or hitch of any kind. Not a lamp was fused or damaged. The boiler was admirably tended by the stoker from the Northern Railway. The engine and the whole of the machinery ran perfectly.

The experiments show that, in the transmission of power, ropes and belts when well arranged absorb almost the same amount of power. In presenting this report the President of the commission desires to express his gratitude to his distinguished colleagues, to whose energy and experience the success of these trials is due. In conclusion he begs the President of the Société to unite with him in conveying to all his most cordial thanks, and to add the thanks of the administrative council to those of the civil engineering committee and of the members of the Société Industrielle du Nord de la France.

V. DUBREUIL, Engineer,
President of the Civil Engineering Committee
and of the Commission for these trials.

This report is approved by Messrs. Bonet, Capper, Chapuy, de Cuyper,* Dujardin, Gœrich, Gruson, Laussedat, Olry, Neu, Schmidt, Vigneron, Villain, and Witz.

* In line 13 of Table 13, page 620, giving the slip, M. de Cuyper considers that the thickness of the belt should have been taken into account in calculating the diameters of contact: the slip of the belts would then have compared more favourably with that of the ropes.

TABLE 1.

Engine, Fly-wheels, Pulleys.

Horizontal Compound Engine.		High-pressure Cylinder.	Low-pressure Cylinder.
Diameter of piston . . .		16·34 inches	29·53 inches
Diameter of piston-rod . .		2·95 inches	2·95 inches
Cross section of piston-rod .		6·85 square ins.	6·85 square ins.
Effective area of piston	front	202·81 square ins.	677·92 square ins.
	back	209·66 square ins.	684·77 square ins.

Length of stroke	31·497 inches	=	2·625 feet.
Diameter of Fly-wheel for Ropes . .	196·30 ,,	=	16·358 ,,
,, ,, ,, ,, Belt . . .	196·58 ,,	=	16·382 ,,
Diameter of Pulley for Ropes . .	58·86 ,,	=	4·905 ,,
,, ,, ,, ,, Belt . . .	59·06 ,,	=	4·922 ,,
Breadth of Fly-wheel and Pulley for Ropes	13·08 ,,		
,, ,, ,, ,, ,, ,, Belt	18·48 ,,		
Distance between centres of Fly-wheel and Pulley . . .			30·184 feet.

TABLE 2.

Values of Coefficient K,

for converting Mean Effective Pressure M *into Indicated Horse-Power* ;
I.H.P. = K × M.

Cylinders		HIGH-pressure. Front.	HIGH-pressure. Back.	LOW-pressure. Front.	LOW-pressure. Back.	Revolutions per minute.
Indicator Spring, lbs. per square inch per inch compression	nominal	45·19	45·19	12·05	12·05	
	actual	43·81	43·03	11·74	11·83	
Piston area in square inches × stroke in feet ÷ 33,000		0·01613	0·01668	0·05397	0·05446	
		K	K	K	K	Revs.
K = revolutions per minute × piston area × stroke ÷ 33,000		1·255	1·298	4·195	4·238	77·84
		1·275	1·317	4·261	4·303	79·03
		1·275	1·318	4·259	4·305	79·08
		1·278	1·321	4·272	4·314	79·23
		1·265	1·308	4·228	4·272	78·46

TABLE 3.—*Trial with Ropes.* 7 *August* 1894.
Revolutions of Engine and Dynamo.

Time p.m.	ENGINE.			DYNAMO.*		
	Reading of Counter.	Revolutions Difference.	Revolutions Per minute.	Reading of Counter.	Revolutions Difference.	Revolutions Per minute.
H. M.	No.	Revs.	Revs.	No.	Revs.	Revs.
3 42	13,595			8,730		
		1,078	77·00		1,218	261·00
3 56	14,673			9,948		
		691	76·77		782	260·66
4 5	15,364			10,730		
		782	78·20		870	261·00
4 15	16,146			11,600		
		1,018	78·32		1,132	261·23
4 28	17,164			12,732		
		775	77·50		869	260·70
4 38	17,939			13,601		
		697	77·44		783	261·00
4 47	18,636			14,384		
		848	77·09		958	261·27
4 58	19,484			15,342		
		860	78·18		958	261·27
5 9	20,344			16,300		
		1,092	78·00		1,219	261·22
5 23	21,436			17,519		
		1,096	78·30		1,216	260·57
† 5 37	22,532			18,735		
		775	77·50		868	260·40
5 47	23,317			19,603		
		865	78·64		955	260·45
5 58	24,182			20,558		
	Mean §		77·84	Mean §		260·91

* The Dynamo Counter was geared to run at one-third the speed of the dynamo.

† Up to 5.23 the Engine Counter missed several times. From 5.37 to 5.58 it ran without failure.

§ The mean is obtained by dividing the total number of revolutions by the total duration of the trial.

TABLE 4.—*Trial with Ropes.* 7 *August* 1894.

Mean Pressure and Horse-Power from Indicator Diagrams.

Mean pressure of steam at engine 88·65 lbs. per square inch.

Time	HIGH-PRESSURE Cylinder.				LOW-PRESSURE Cylinder.				Total
	Front end.		Back end.		Front end.		Back end.		Indicated
p.m.	Mean Pressure per sq. in.	Indicated Horse-Power.	Mean Pressure per sq. in.	Indicated Horse-Power.	Mean Pressure per sq. in.	Indicated Horse-Power.	Mean Pressure per sq. in.	Indicated Horse-Power.	Horse-Power.
H. M.	Lbs.	I.H.P.	Lbs.	I.H.P.	Lbs.	I.H.P.	Lbs.	I.H.P.	I.H.P.
3 40	29·6	37·16	32·1	41·69	9·9	41·64	10·2	43·48	163·97
3 50	29·3	36·86	32·0	41·56	9·7	40·72	10·4	44·01	163·15
4 0	27·8	34·86	30·2	39·25	9·5	40·02	10·0	42·41	156·54
4 10	29·5	36·88	31·3	40·68	9·8	41·30	10·1	43·01	161·87
4 20	27·4	34·39	29·6	38·46	9·6	40·33	10·0	42·59	155·77
4 30	28·8	36·16	31·3	40·59	9·8	41·12	10·2	43·13	161·00
4 40	29·4	36·95	29·9	38·79	9·5	39·90	9·9	41·82	157·46
4 50	29·3	36·77	30·5	39·59	9·4	39·44	9·8	41·47	157·27
5 0	31·1	39·07	29·7	38·57	9·3	38·97	9·5	40·40	157·01
5 10	29·9	37·50	29·9	38·88	9·1	38·10	9·5	40·28	154·76
5 20	27·7	34·76	33·1	43·01	9·6	40·13	10·0	42·23	16·130
5 32	30·9	38·81	31·6	41·03	9·3	38·86	9·8	41·59	160·29
5 43	30·0	37·68	31·5	40·90	9·8	41·07	10·2	43·24	162·89
5 56	27·6	34·69	31·7	41·21	9·8	41·19	10·0	42·41	159·50
6 0	29·7	37·25	30·8	40·02	9·6	40·13	10·0	42·41	159·81
Means	29·21	36·65	31·01	40·28	9·58	40·18	9·97	42·29	159·42

TABLE 5.—*Trial with Cotton Belt (Lechat).* 8 *August* 1894.
Revolutions of Engine and Dynamo.

Time a.m.	ENGINE. Reading of Counter.	ENGINE. Revolutions Difference.	ENGINE. Revolutions Per minute.	DYNAMO.* Reading of Counter.	DYNAMO.* Revolutions Difference.	DYNAMO.* Revolutions Per minute.
H. M.	No.	Revs.	Revs.	No.	Revs.	Revs.
9 0	5,226			28,165		
		1,184	78·93		1,305	261·00
9 15	6,410			29,470		
		1,412	78·45		1,554	259·00
9 33	7,822			31,024		
†		897	79·74		987	263·20*a*
9 43	8,719			32,011		
		957	79·75		1,052	263·00
9 55	9,676			33,063		
‡		687	78·52		757	259·54*b*
10 3	10,363			33,820		
		874	79·09		962	262·38
10 14	11,237			34,782		
		1,347	79·24		1,483	261·70
10 31	12,584			36,265		
		1,186	79·06		1,306	261·20
10 46	13,770			37,571		
		1,263	78·94		1,390	260·64
11 2	15,033			38,961		
		1,181	78·73		1,301	260·20
11 17	16,214			40,262		
		949	79·08		1,044	261·00
11 29	17,163			41,306		
	Mean §		79·05	Mean §		261·08

* The Dynamo Counter was geared to run at one-third the speed of the dynamo.

† From 9.33 to 9.43 the actual interval was more than ten minutes, as the watch which was used for timing stopped for about $1\frac{1}{4}$ minute.

‡ From 9.55 to 10.3 another watch was used, which was not exactly in agreement with the first. About $\frac{2}{3}$ minute must be added for this.

§ The mean speed for the trial must be reckoned on the 131 minutes from 9.0 a.m. to 9.33; from 9.43 to 9.55; and from 10.3 to 11.29. The total revolutions counted in the whole table were actually accomplished in 151 minutes instead of 149.

a including the additional $1\frac{1}{4}$ minute. *b* including the additional $\frac{2}{3}$ minute.

TABLE 6.—*Trial with Cotton Belt (Lechat).* 8 *August* 1894.

Mean Pressure and Horse-Power from Indicator Diagrams.

Mean pressure of steam at engine 89·42 lbs. per square inch.

Time a.m.	HIGH-PRESSURE Cylinder.				LOW-PRESSURE Cylinder.				Total Indicated Horse-Power.
	Front end.		Back end.		Front end.		Back end.		
	Mean Pressure per sq. in.	Indicated Horse-Power.	Mean Pressure per sq. in.	Indicated Horse-Power.	Mean Pressure per sq. in.	Indicated Horse-Power.	Mean Pressure per. sq. in.	Indicated Horse-Power.	
H. M.	Lbs.	I.H.P.	Lbs.	I.H.P.	Lbs.	I.H.P.	Lbs.	I.H.P.	I.H.P.
9 10	28·0	35·66	31·3	41·31	9·3	39·46	9·9	42·70	159·13
9 20	29·1	37·07	31·1	40·99	9·1	38·87	9·8	42·22	159·15
9 30	29·1	37·07	31·7	41·85	9·1	38·98	9·9	42·82	160·72
9 40	27·4	34·96	30·9	40·68	9·5	40·64	9·6	41·46	157·74
9 50	27·9	35·55	31·6	41·70	9·4	40·16	9·5	41·02	158·43
10 0	29·3	37·33	30·7	40·52	9·3	39·81	9·8	42·34	160·00
10 10	29·4	37·47	32·7	43·13	8·9	37·80	9·4	40·54	158·94
10 20	30·2	38·52	32·0	42·14	9·2	39·22	9·5	40·77	160·65
10 30	31·3	39·91	33·9	44·74	9·0	38·28	9·3	40·11	163·04
10 40	30·6	38·96	34·8	45·81	8·8	37·45	9·3	40·05	162·27
10 50	30·9	39·45	32·7	43·13	8·7	37·10	9·0	38·79	158·47
11 0	30·8	39·32	33·6	44·25	9·0	38·28	9·1	38·97	160·82
11 10	29·2	37·20	32·7	43·08	9·1	38·63	9·3	39·93	158·84
11 20	29·3	37·40	31·3	41·26	9·1	38·98	9·4	40·29	157·93
11 30	30·0	38·30	32·2	42·39	8·9	38·16	9·3	40·15	159·00
Means	29·50	37·61	32·21	42·47	9·09	38·79	9·47	40·81	159·67

TABLE 7.—*Trial with Leather Belt (Lemaire).* 8 *August* 1894.
Revolutions of Engine and Dynamo.

Time p.m.	ENGINE. Reading of Counter.	ENGINE. Revolutions Difference.	ENGINE. Revolutions Per minute.	DYNAMO.* Reading of Counter.	DYNAMO.* Revolutions Difference.	DYNAMO.* Revolutions Per minute.
H. M.	No.	Revs.	Revs.	No.	Revs.	Revs.
4 26	24,438			49,239		
		1,504	79·16		1,653	261·00
4 45	25,942			50,892		
		1,497	78·78		1,645	259·75
5 4	27,439			52,537		
		1,356	79·76		1,491	263·10
5 21	28,795			54,028		
		945	78·75		1,039	259·75
5 33	29,740			55,067		
		1,501	79·00		1,649	260·37
5 52	31,241			56,716		
		1,186	79·07		1,303	260·60
6 7	32,427			58,019		
		1,418	78·77		1,560	260·00
6 25	33,845			59,579		
		863	78·45		959	261·52
6 36	34,718			60,538		
		949	79·08		1,042	260·50
6 48	35,667			61,580		
	Mean §		79·08	Mean §		260·72

* The Dynamo Counter was geared to run at one-third the speed of the dynamo.

§ The mean is obtained by dividing the total number of revolutions by the total duration of the trial.

TABLE 8.—*Trial with Leather Belt (Lemaire).* 8 *August* 1894.

Mean Pressure and Horse-Power from Indicator Diagrams.

Mean pressure of steam at engine 88·61 lbs. per square inch.

Time p.m.	HIGH-PRESSURE Cylinder.				LOW-PRESSURE Cylinder.				Total Indicated Horse-Power.
	Front end.		Back end.		Front end.		Back end.		
	Mean Pressure per sq. in.	Indicated Horse-Power.	Mean Pressure per sq. in.	Indicated Horse-Power.	Mean Pressure per sq. in.	Indicated Horse-Power.	Mean Pressure per sq. in.	Indicated Horse-Power.	
H. M.	Lbs.	I.H.P.	Lbs.	I.H.P.	Lbs.	I.H.P.	Lbs.	I.H.P.	I.H.P.
4 30	29·1	37·08	27·9	36·85	9·0	38·59	10·0	43·09	155·61
4 40	29·1	37·08	27·9	36·76	9·6	40·78	10·2	43·92	158·54
4 50	28·8	36·69	28·8	37·99	9·2	39·18	10·2	43·92	157·78
5 0	29·0	36·95	28·6	37·71	9·5	40·43	10·2	43·92	159·01
5 13	29·2	37·23	27·3	36·04	9·2	39·36	9·8	42·36	154·99
5 19	28·9	36·82	27·4	36·18	9·4	40·07	9·9	42·73	155·80
5 30	29·0	37·03	29·2	38·51	9·4	40·07	9·9	42·73	158·34
5 40	29·8	38·02	30·0	39·58	9·4	39·95	10·1	43·33	160·88
5 50	29·1	37·08	28·3	37·38	9·4	40·07	10·0	42·97	157·50
6 0	29·5	37·66	28·7	37·78	9·2	39·36	9·8	42·36	157·16
6 10	27·5	35·10	29·3	38·60	9·4	39·95	10·1	43·33	156·98
6 20	28·1	35·85	31·4	41·39	9·8	41·96	10·5	45·20	164·40
6 30	27·9	35·64	30·6	40·33	9·8	41·61	10·3	44·28	161·86
6 40	27·6	35·24	29·5	38·86	9·7	41·37	10·2	43·82	159·29
6 50	28·7	36·56	30·5	40·20	9·9	42·32	10·5	45·38	164·46
Means	28·75	36·66	29·03	38·28	9·46	40·33	10·11	43·55	158·84

TABLE 9.—*Trial with Leather Belt (Domange).* 9 *August* 1894.
Revolutions of Engine and Dynamo.

Time a.m.	ENGINE.			DYNAMO.*		
	Reading of Counter.	Revolutions Difference.	Revolutions Per minute.	Reading of Counter.	Revolutions Difference.	Revolutions Per minute.
H. M.	No.	Revs.	Revs.	No.	Revs.	Revs.
9 8	5,346			5,904		
		1,890	78·75		2,080	260·00
9 32	7,236			7,984		
		1,199	79·93		1,319	263·80
9 47	8,435			9,303		
		2,069	79·58		2,278	262·80
10 13	10,504			11,581		
		1,494	78·63		1,645	259·73
10 32	11,998			13,226		
		943	78·58		1,039	259·75
10 44	12,941			14,265		
		1,586	79·30		1,745	261·70
11 4	14,527			16,010		
		1,911	79·62		2,108	263·50
11 28	16,438			18,118		
	Mean §		79·23	Mean §		261·73

* The Dynamo Counter was geared to run at one-third the speed of the dynamo.

§ The mean is obtained by dividing the total number of revolutions by the total duration of the trial.

TABLE 10.—*Trial with Leather Belt (Domange).* 9 *August* 1894.

Mean Pressure and Horse-Power from Indicator Diagrams.

Mean pressure of steam at engine 88·78 lbs. per square inch.

Time a.m.	HIGH-PRESSURE Cylinder. Front end. Mean Pressure per sq. in.	HIGH-PRESSURE Cylinder. Front end. Indicated Horse-Power.	HIGH-PRESSURE Cylinder. Back end. Mean Pressure per sq. in.	HIGH-PRESSURE Cylinder. Back end. Indicated Horse-Power.	LOW-PRESSURE Cylinder. Front end. Mean Pressure per sq. in.	LOW-PRESSURE Cylinder. Front end. Indicated Horse-Power.	LOW-PRESSURE Cylinder. Back end. Mean Pressure per sq. in.	LOW-PRESSURE Cylinder. Back end. Indicated Horse-Power.	Total Indicated Horse-Power.
H. M.	Lbs.	I.H.P.	Lbs.	I.H.P.	Lbs.	I.H.P.	Lbs.	I.H.P.	I.H.P.
9 10	29·3	37·43	30·7	40·53	9·4	40·03	9·6	41·48	159·47
9 20	29·9	38·23	32·0	42·30	9·4	40·15	9·7	41·84	162·52
9 30	30·4	38·89	32·2	42·57	8·9	38·13	9·7	42·08	161·67
9 40	29·2	37·37	31·4	41·50	8·6	36·83	9·4	40·39	156·09
9 50	30·7	39·28	30·6	40·43	8·6	36·59	9·4	40·52	156·82
10 0	31·0	39·68	29·7	39·30	8·9	38·01	9·5	41·12	158·11
10 10	30·0	38·34	31·7	41·83	8·8	37·77	9·7	41·84	159·78
10 20	30·9	39·50	31·6	41·77	9·0	38·48	9·9	42·56	162·31
10 30	30·7	39·28	32·2	42·52	8·9	37·89	9·7	41·84	161·53
10 40	30·3	38·69	32·2	42·57	8·8	37·60	9·4	40·72	159·58
10 50	31·0	39·65	32·6	43·04	8·7	37·30	9·6	41·36	161·35
11 0	33·3	42·52	32·2	42·57	8·6	36·95	9·4	40·52	162·56
11 10	32·0	40·87	30·1	39·75	8·6	36·71	9·4	40·76	158·09
11 20	33·2	42·05	30·9	40·83	8·4	35·88	9·4	40·39	159·15
11 30	34·9	44·57	32·1	42·44	8·7	37·18	9·3	40·28	164·47
Means	31·12	39·76	31·48	41·59	8·82	37·70	9·54	41·18	160·23

TABLE 11.—*Trial with Ropes.* 9 *August* 1894.
Revolutions of Engine and Dynamo.

Time p.m.	ENGINE. Reading of Counter.	ENGINE. Revolutions Difference.	ENGINE. Revolutions Per minute.	DYNAMO.* Reading of Counter.	DYNAMO.* Revolutions Difference.	DYNAMO.* Revolutions Per minute.
H. M.	No.	Revs.	Revs.	No.	Revs.	Revs.
3 3	22,707			25,172		
		1,013	77·93			
3 16	23,720			——	1,476	260·00
		318	79·50			
3 20	24,038			26,648		
		1,023	78·70		1,133	261·45
3 33	25,061			27,781		
		865	78·64		957	261·00
3 44	25,926			28,738		
		1,414	78·55		1,567	261·16
4 2	27,340			30,305		
		1,016	78·15		1,126	259·85
4 15	28,356			31,431		
		1,333	78·42		1,478	260·82
4 32	29,689			32,909		
		1,021	78·54		1,131	261·00
4 45	30,710			34,040		
		1,334	78·47		1,478	260·82
5 2	32,044			35,518		
		1,255	78·44		1,390	260·63
5 18	33,299			36,908		
		1,177	78·48		1,303	260·60
5 33	34,476			38,211		
	Mean §		78·46	Mean §		260·78

* The Dynamo Counter was geared to run at one-third the speed of the dynamo.

§ The mean is obtained by dividing the total number of revolutions by the total duration of the trial.

TABLE 12.—*Trial with Ropes.* 9 *August* 1894.

Mean Pressure and Horse-Power from Indicator Diagrams.

Mean pressure of steam at engine 89·46 lbs. per square inch.

Time	HIGH-PRESSURE Cylinder.				LOW-PRESSURE Cylinder.				Total Indicated Horse-Power.
	Front end.		Back end.		Front end.		Back end.		
p.m.	Mean Pressure per sq. in.	Indicated Horse-Power.	Mean Pressure per sq. in.	Indicated Horse-Power.	Mean Pressure per sq. in.	Indicated Horse-Power.	Mean Pressure per sq. in.	Indicated Horse-Power.	
H. M.	Lbs.	I.H.P.	Lbs.	I.H.P.	Lbs.	I.H.P.	Lbs.	I.H.P.	I.H.P.
3 8	29·7	37·59	29·6	38·70	9·5	40·11	10·3	44·54	160·94
3 20	29·8	37·68	30·5	39·94	9·4	39·76	10·1	43·94	161·32
3 30	29·4	37·20	28·2	36·97	9·2	39·05	10·1	42·99	156·21
3 40	30·2	38·24	29·4	38·43	9·3	39·52	9·9	42·99	159·18
3 50	29·6	37·41	29·5	38·61	9·2	38·76	10·0	42·51	157·29
4 0	31·0	39·20	30·1	39·45	9·0	38·23	9·9	42·87	159·75
4 10	30·8	39·03	29·1	38·03	9·1	38·59	9·6	42·15	157·80
4 20	30·6	38·77	30·0	39·23	8·9	37·76	9·4	41·08	156·84
4 30	31·0	39·24	29·4	38·43	8·9	37·76	9·4	40·36	155·79
4 40	31·0	39·20	30·1	39·37	8·8	37·20	9·5	40·36	156·22
4 50	31·1	39·43	29·9	39·18	8·5	36·06	9·6	40·60	155·27
5 0	31·2	39·55	30·5	39·90	9·0	38·11	9·9	41·04	158·60
5 10	32·5	41·19	30·7	40·23	8·9	37·53	9·8	42·15	161·10
5 20	31·5	39·82	31·3	41·01	9·1	38·46	9·7	41·79	161·08
5 30	32·4	40·96	31·6	41·36	8·8	37·06	9·7	41·44	160·82
Means	30·79	38·97	29·99	39·25	9·04	38·26	9·84	42·05	158·54

TABLE 13.—*Summary of Trials with Ropes and Belts.*

Rope Fly-wheel 16·358 feet diameter, and Pulley 4·905 feet diameter, grooved for five Ropes of 1¾ inch diameter.
Belt Fly-wheel 16·382 feet diameter, and Pulley 4·922 feet diameter, for Belt of 17¾ inches width.

Number of trial	1	2	3	4	5
Ropes or Belt	Ropes.	Belt.	Belt.	Belt.	Ropes.
Material	Manila.	Cotton.	Leather.	Leather.	Manila.
Manufactured by	Saint.	Lechat.	Lemaire.	Domange.	Saint.
Date of trial, August 1894	7th aft.	8th morn.	8th aft.	9th morn.	9th aft.
Duration of trial . . . minutes	136	151	142	140	150
Indicated Horse-Power . . . I.H.P.	159·42*	159·67	158·84	160·23	158·54
Mean speed of Engine . . . revs. per min.	77·84*	79·05	79·08	79·23	78·46
" " " Dynamo . . . revs. per min.	260·91	261·08	260·72	261·73	260·78
Ratio of Fly-wheel diameter to Pulley diameter at contact	3·335	3·329	3·329	3·329	3·335
C Circumferential speed of Fly-wheel . feet per sec.	66·64	67·75	67·78	67·82	67·16
c " " " Pulley . feet per sec.	66·94	67·23	67·13	67·29	66·93
Slip, $100 \times (C-c) \div C$ . . . per cent.	−0·051	+0·780	+0·961	+0·780	+0·329
Area of cross section of Ropes or Belt — inches	1·6×5	17·72×0·374	17·72×0·492	17·40×0·433	1·6×5
Area of cross section of Ropes or Belt — square inches	=8·00	=6·63	=8·72	=7·54	=8·00
Tension on Ropes or Belt at fly-wheel . lbs. per sq. inch	157·17	176·08	132·98	155·02	155·02
" " " pulley . lbs. per sq. inch	157·17	177·35	134·40	156·16	156·45
Weight of Ropes or Belt . . . lbs.	418·8	332·8	330·7	293·2	418·8
Mean Potential Difference (see footnote page 604) . volts	94·00	93·88†	93·83‡	94·00	94·00
Relative Power absorbed, taking trial 5 as 100·00	100·58	100·87	100·37	101·07	100·00

* Owing to the failure of the engine counter in trial 1, which perhaps explains the apparently negative slip, the indicated horse-power and speed of engine here given are too low; by counting with a chronometer the values obtained were 160·72 I.H.P. and 78·49 revolutions per minute. The engine and dynamo were new, and had previously run for only two hours since their erection the day before the trial; the mechanical losses would therefore be greater, and this is confirmed by the result of trial 5.

† The last five readings of the voltmeter were 93·66 instead of 94, which gives a mean of 93·88 volts for the fifteen readings.

‡ Ten readings out of the fifteen were 93·74 instead of 94, which gives a mean of 93·83 volts. (See footnote page 604.)

OBSERVATIONS ON THE LILLE EXPERIMENTS ON THE COMPARATIVE EFFICIENCY OF ROPES AND BELTS FOR THE TRANSMISSION OF POWER.

By Professor DAVID S. CAPPER, of London.

Experiments on the Efficiency of Ropes and Belts for the Transmission of Power have been few; and for the most part such knowledge as is at present possessed on this subject has been indirectly derived. The investigation is perhaps as important as any in its influence upon industrial economy; but the problems involved are complex, and experiments in order to be conclusive must be on such a scale as necessarily to involve a large expenditure both of time and of money. This has hitherto paralyzed effort; and the Société Industrielle du Nord de la France are to be congratulated upon the enterprise and liberality of certain of their members, whereby experiments on a large scale have been rendered possible. All the arrangements were carried out and all the expense was borne by French engineers; but with a courtesy worthy of general imitation the Société invited the Institution of Mechanical Engineers to send a member to represent them at the trials. At the request of the Council the author attended in that capacity the preliminary meeting held in November 1893; and being then elected one of six additional members of the Commission, was present at the subsequent meetings and at the trials.

The programme, drawn up by the President of the Commission and submitted to an early meeting, confined the scope of the trials to a direct comparison between the gross power required to overcome a fixed resistance through ropes and through belts. With a view to obtaining an absolute determination of the power absorbed in the gearing, the author suggested that the fly-wheel should be designed so that brake tests could be carried out, and that a series of such

trials should be undertaken. But after consideration of this proposal, it was decided by those who were responsible for carrying out the experiments to adhere to the original limits. A further suggestion by M. Neu—that the engine might be eliminated altogether by employing three dynamos, the second of which could be driven from the first, and, running as a motor, could drive the third through the rope and belt gearing—was found impracticable, owing to the extent and cost of the installation which it would involve. Thus limited, the experiments were arranged and carried out admirably, and with all possible precautions.

The engine is of the horizontal two-crank compound type, and was constructed by Messrs. Dujardin and Co. to drive their workshops. It was specially fitted with twin fly-wheels for the trials. The cut-off is effected by vacuum plungers, controlled through a trip gear by the governor. An injection condenser maintained a constant vacuum, the back pressure in the low-pressure cylinder being less than 3 lbs. per square inch. The air and feed pumps are worked off the high-pressure cross-head.

Indicators.—Four Tabor indicators were used, and previously to the trials their springs were calibrated under steam by M. Bonet against two standard gauges. The corrected scales are given in Table 2, page 609, and these have been employed in all cases for calculating the horse-powers. For all the trials the position of the indicators remained unaltered; and as each end of each cylinder was indicated by the same observer throughout, the observations could be strictly compared with one another. The indicator pistons were well oiled every ten minutes; and all four diagrams were taken simultaneously at the instant when the signal was given that the resistance was steady at the required value. Every care was taken to prevent inaccuracies due to unequal pressure of the pencil; and the diagrams were remarkably uniform, and free from any indications of such defects. The author took a number of diagrams in which pencil contact was maintained for half a minute; and the outline showed a scarcely perceptible thickening, the greatest fluctuations taking place, as would be expected, in the high-pressure cylinder.

Boiler.—The boiler was of the locomotive type, fitted with steel tubes having internal feathers for increasing the heating surface. The stoking was excellent, and the boiler pressure was remarkably steady from beginning to end of the trials.

Dynamo.—The dynamo was of the four-pole type, the armature being Gramme-wound with 252 turns of rectangular copper, forming three sections. The armature resistance was 0·001585 ohm. The field magnets were shunt-wound, the resistance of the field winding being 4·642 ohms; and the air space between the core and the pole-pieces was 0·787 inch. The efficiency of the whole system, E.H.P. ÷I.H.P., was rather over 68½ per cent., measured on the volt and ampère meters. The rated output of the dynamo was 1,200 ampères at 113 volts, or 135·6 kilowatts, when running at a speed of 265 revolutions per minute.

Fly-wheel and Pulley.—The breadth of the fly-wheel and pulley for the ropes was 13·08 inches, and for the belts 18·48 inches, as shown in Figs. 1 to 5, Plate 151.

Results of the Trials.—In the summary table, page 620, will be found the means of the fifteen observations taken during each trial. The maximum mean, 160·23 horse-power, was developed in the trial of the Domange leather belt, and the minimum mean 158·54 in the second trial of the ropes. The difference is 1·05 per cent. of the maximum mean. From the method adopted in the experiments, this represents the whole difference found between the efficiency of the two plans. On referring to the table of details however, it will be seen that during each experiment a greater variation of power was observed than this mean. In one trial the difference between individual readings reached 5·7 per cent., while the least variation in any trial was 3·1 per cent. As each observation is complete in itself, and as the resistance was constant to 0·4 per cent. throughout the trials, and every possible precaution was taken to ensure uniformity of conditions, it is evident that a constancy to within about 3 or 4 per cent. is the utmost which can be relied upon. The indicators being carefully calibrated, and used only for comparison, would give results true within these limits; but the unknown

mechanical efficiency of both engine and dynamo, the errors of observation, and the possible changes in the actual amount of the power absorbed in the gearing, must clearly have affected the consecutive readings to an amount sufficient to produce the larger variations. It appears therefore that the difference between the efficiencies of the rope and the belt gearing used in the trials was inappreciable within these limits; and to have practically demonstrated this fact is a result of sufficient value, although the more important question, of the actual power absorbed by the gearing, is no nearer solution.

Slip.—In measuring the slip of the belts the effective radius has been taken from the centre of the shaft to the surface of the fly-wheel and pulley rims. The thickness of the belt has thus been neglected. If the belt thickness be added to the diameter of the fly-wheel and pulley, the slip would be more correctly stated as follows:—

TABLE 14.—*Slip of Belt.*

Description of Belt		Cotton. Lechat.	Leather. Lemaire.	Leather. Domange.
Fly-wheel, effective diameter	feet	16·413	16·423	16·418
„ „ circumference	feet	51·563	51·594	51·579
„ circumferential velocity,	ft. per sec.	67·934	68·001	68·109
Pulley, effective diameter	feet	4·953	4·963	4·958
„ „ circumference	feet	15·560	15·592	15·576
„ circumferential velocity,	feet per sec.	67·708	67·751	67·945
Slip of Belt, actual	feet per second	0·226	0·250	0·164
„ „ percentage	per cent.	0·333	0·368	0·241

The speed of slip reckoned as above for the belts is from about 10 to 15 feet per minute.

With regard to the ropes, it is uncertain to what depth they sink into the grooves when running under load. In Table 13 the slip of the ropes has been calculated on the assumption that the effective radius is the distance between the centre of the shaft and the centre

of the rope when at rest. But on removing the ropes the author found that the polished ring showing where rubbing had taken place was 5–8ths inch broad, and lay within that radius, as shown in Fig. 3, Plate 151. It seems probable therefore that the true effective radius lies within the limits assigned to it; and as a small decrease in the effective circumference would considerably increase the slip, it seems doubtful, in the absence of special experiments, what is the real slip of the ropes.

Previous Experiments. Morin.—The earliest belt experiments on record were made by General Morin, who in 1834 investigated the laws governing the friction of leather belts on wooden drums of three different diameters, and on cast-iron pulleys. From each end of a black curried leather belt, suspended over a fixed drum, were hung weights, which at one end were gradually increased until slipping commenced. The belt had been made pliable by previous use; and Morin estimated that the loss due to stiffness might be neglected in comparison with the friction of slipping. With weights of which the mean varied between 41 and 125 lbs. per inch of width, and with arcs of contact varying within a range of proportion of 1 to 8, the coefficient of friction remained sensibly constant. In another series of trials, dynamometers were inserted on both sides of an endless vertical belt, which passed round a pulley and an oak drum. Weights were hung in a scale-pan attached to the circumference of the drum, which with the pulley was allowed to rotate as far as the dynamometers would permit. It was thus possible to measure the tensions on the two sides of the belt, under the three conditions of rest and motion and when about to slip. The normal tension could be increased by tightening the ends of the belt when at rest. Loads increasing from 0 to 175 lbs. per inch of width caused no appreciable variation in the sum of the two tensions until slipping began. The greatest single tension applied was 174 lbs., the least 11 lbs., and the sum reached a maximum of 206 lbs. The coefficient of friction varied between 0·544 and 0·596, the mean being 0·573.

Briggs and Towne.—In the journal of the Franklin Institute for 1868 a paper was published giving an account of experiments made

by Messrs. Briggs and Towne upon the coefficient of friction between leather belts and cast-iron pulleys, and upon the strength of belts. Pulleys 12 inches and $23\frac{5}{8}$ and 41 inches in diameter were employed, all of them having been in workshop use for some years previously. The belts were in various conditions: some were new; others had been in use some time and were in good running order; and others, although not completely worn out, were weakened by wear. The arrangements were similar to those of Morin's first experiments, scale-pans being attached to both ends of the belt suspended freely over a stationary pulley; in one scale-pan the weight was constant, and in the other weights were gradually added until the belt slipped freely; the load was then recorded. For all the experiments the velocity of slipping was about 200 feet per minute, and care was taken that the weight should be only just sufficient to cause free sliding without acceleration. The arc of contact was 180° for all the experiments. With tensions of 7 to 110 lbs. per inch of width, the mean of 168 experiments gave a calculated coefficient of 0·58, thus confirming Morin's results. As it was found impracticable to imitate exactly the working conditions where free slipping should not take place, Mr. Towne considers that a coefficient calculated on the assumption that the working tensions are 60 per cent. of those applied in his experiments, or 0·42, will better represent the working value. In arriving at this result, no account was taken of the velocity of the belt, which was inappreciable, or of the dimensions of the pulley. The ultimate strength of leather belts of 7-32nds or 0·219 inch thickness Mr. Towne found to be about 200 lbs. per inch of width, when the rupture was through the laced joints; when through the rivet holes of the splices, a strength more than half as large again was obtained; and when through the solid leather, it reached 675 lbs. per inch of width.

Leloutre.—In 1878 an extensive series of experiments was made by M. Leloutre upon the elongation and breaking strain of leather driving belts, and the slipping of belts and cords. By attaching weights to narrow thongs cut from different belts, he found that the maximum resistance to stretching of ordinary leather is at a load of 850 lbs. per square inch. At this load the most economical results

will be attained. The slip he determined in the same manner as Morin, by hanging belts with both ends free over a stationary polished pulley. By carefully manipulating the weights at the two ends he obtained constant speeds of slip down to as slow as 3-8ths inch per minute. The diameter of the pulleys varied from 4 inches to 8 feet, and the width of belt from 3-8ths inch to 12 inches. The arc of contact was from 180° to 1,260°. The ropes were $1\frac{1}{4}$ inch diameter, and were tried both with plain pulleys and with circular and V-shaped grooves. The coefficient thus found for new leather belts was 0·155, for old greasy belts 0·20 to 0·22; for the same belts on unpolished pulleys it rose to 0·33. With moist leather the coefficient was sometimes as low as 0·12. With ropes and smaller cords its value was about 0·070 to 0·075. In replacing with belting some large spur wheels, through which 750 I.H.P. was passed, M. Leloutre had the opportunity of making careful trials both before and after the change. The total loss of power in engine and gearing with the spur wheels was 208 H.P., and with the belts 184 H.P. Reckoned on the gross power, the belts were therefore about 3 per cent. more efficient than the wheels. As it has been shown by careful experiments made by Mr. Wilfred Lewis that the average efficiency of well-cut spur gearing is about 93 per cent., M. Leloutre's experiment would indicate an efficiency of about 95 to 96 per cent. for the belting.

Lewis.—In 1886 experiments were carried out by Mr. Wilfred Lewis for Messrs. Sellers and Co., to determine the slip and efficiency of belt gearing. A large number of observations with different kinds of belts showed that with belting properly arranged the slip should not exceed $1\frac{1}{2}$ to 2 per cent. If however slipping occurs to any considerable extent, a black oily deposit accumulates, and the coefficient being reduced the slip is largely increased. By measuring the torsional moment required to run a straight belt at different speeds, the total efficiency of the gearing was calculated to be 97 per cent. of the gross load, thus practically confirming M. Leloutre's direct experiment. Contrary to the theory of Poncelet and the experiments of Morin and Briggs, Mr. Lewis found that the sum of the tensions does not remain constant, but increases

with the load as much as 33 per cent. with vertical belts. As the efficiency and the slip were the same, whether thick or thin belts were employed, Mr. Lewis could detect no loss from stiffness. He therefore concludes that economy depends chiefly upon slip and journal friction.

Lanza.—Professor Lanza, also in 1886, supplemented the information obtained by previous experimenters upon slip, by seeking to determine:—first, what is the average speed of slip under ordinary practical conditions of working; second, what is the coefficient of friction obtained with the average speed of slip; third, what is the variation of the coefficient with different kinds of pulleys and belts. By careful experiment he finds that the average speed of slip under ordinary working conditions is from 3 to 12 feet per minute; and at that speed the coefficient of friction has a mean value of 0·27.

Fauquier.—Further information has been gained by a series of trials made by M. Fauquier, the results of which are recorded in the Proceedings of the Société des Ingénieurs Civils, 1893, page 558. With a smooth-rimmed pulley running on carefully prepared bearings he determined the weight required to maintain a constant speed of rotation, when attached alternately to loaded belts and loaded ropes passing round the rim. The added effect of the grooves of a rope pulley was determined by measuring the moment of resistance due to the sticking of the rope in the groove. Pulleys of three different diameters were tried. From his results he derives a formula by which the loss of power due to the stiffness of the ropes and belts may be calculated; and concludes that rope gearing absorbs from one and a half to three times the total power that is lost in belt gearing. This he attributes chiefly to stiffness; but it must be remembered that the measurements upon which he relies are of necessity liable to large proportionate errors. His results must therefore be received with caution in the light of the Lille results.

Pearce.—Messrs. Pearce Brothers of Dundee also made a number of experiments in 1884 to determine the coefficient of friction between ropes and grooved pulleys. With ungreased pulleys the coefficient varied between 0·57 and 0·88; with greased pulleys between 0·38 and 0·41.

Conclusion.—In almost all these experiments the chief object has been to determine the limit of load under ordinary working conditions, beyond which a belt will slip upon its pulley. The work of Morin left out of account the effect of speed of slip upon the frictional coefficient; and although Messrs. Briggs and Towne recognised its influence, they were unable to carry out experiments of a satisfactory kind at the speeds of slip due to the elasticity of belts under ordinary working conditions. Other experimenters, working at lower speeds of slip, obtained conflicting results; and it was not until 1882, when Professor Holman experimented at varying speeds of slip with the express object of finding the cause of the discrepancies, that the coefficient was known to vary from 0·58, the value obtained by Morin and Mr. Towne, down to 0·12 when the speed of slip was sufficiently reduced. Since then Professor Lanza has set all doubt at rest by a careful and elaborate series of tests, in which the average speed of slip under ordinary conditions has been determined, and the value of the coefficient of friction for that speed found to be 0·27, a value which Mr. Towne accepts as more accurate than that which he was forced to deduce without direct confirmation. It is therefore possible to ensure that no excessive loss shall occur from slip. But there still remain residual losses—slip due to elasticity, work in overcoming the stiffness of belts, reduction of the coefficient at high speeds by centrifugal action and by air—about which very little is definitely known.

The experiments of Mr. Lewis and M. Leloutre tend to show that the total loss in well-designed belt gearing does not exceed 3 or 4 per cent. of the gross power transmitted; and M. Fauquier has investigated the losses due to stiffness, with results which require confirmation before they can be deemed conclusive, and with which the observations of Mr. Lewis directly conflict.

By the Lille trials it has been shown that ropes are practically as efficient as belts, at any rate at the speeds and powers there tried; though some doubt has been cast upon the actual value as previously determined of the losses in belt gearing, from the fact that the variation which was found between individual observations at Lille exceeded 3 per cent. It is to be regretted that it was not found

possible with such a unique installation to extend the limits of the research; but it must be admitted that the difficulties were great, and the increase in the outlay would probably have been large.

In conclusion the author desires to express his thanks to M. Dubreuil, M. Dujardin, and the members of the Commission and of the experimental staff, for the kindness which was shown him on all occasions, and for the ungrudging manner in which facilities were afforded him for acquiring information upon all that concerned the trials.

Discussion.

Professor Capper drew attention to the specimens which had been sent in illustration of the Report: pieces of belting from M. Domange, M. Lechat, and Messrs. Lemaire and Son; and rope from Messrs. Saint Brothers. He did not wish it to be imagined that the brief summary he had given of previous experiments (pages 625–8) was in any way an exhaustive review of all the experiments which had been made. He had selected those experiments which seemed to him to bear most directly on the efficiency of rope and belt driving; and if by this means any information could be elicited as to additional experiments, the value of the discussion would be greatly enhanced.

Mr. James Platt, Member of Council, was sure the Members must all feel much obliged to their French neighbours for the enterprising manner in which they had carried out these experiments; and to Professor Capper for the great pains he had taken in summarising the results. It was a great pity however that the experiments could not have been further extended, and the rope and belt gearing tested at different speeds. Some few years ago he went

northwards to see some rope driving in Lancashire, where the speed of the ropes was something like 6,000 feet per minute, whereas in the Lille experiments it was only 4,000 feet per minute; and the engineers who were introducing the higher speed found that, as the speed of the ropes increased, the steadier was the driving and the better were the results. The centrifugal force seemed to take away a great deal of the friction from the grooves in the pulleys, and the ropes ran as steady as a line; there was no vibration or undulation at all in the sag. At that time he was told they intended going up to 7,000 feet per minute; but he had not followed their progress since, and he did not know what the result of time had been in their experience. So far however it went to show that, the higher the velocity, the greater was the advantage of rope driving. All engineers knew the trouble there was with belt gearing from the laps of the joints; and he had himself had the same experience as others in this respect. When called in to advise as to irregularity of engines and driving gear, he had often found it was due to the belt driving the governor. In these days of course no good engine was made with a belt-driven governor; but formerly it was so, and there was consequently an up and down motion of the governor every time the belt joint went over the driving pulley or the driven pulley. Besides this, there was also the difficulty with belts of getting a joint which would not affect the safety of the belt itself, as well as of the shafting, in passing over the two pulleys. Ropes of course had not that disadvantage; and as far as his experience went, rope gearing was the best for high speeds. Probably some of the Lancashire members would be able to give some information about rope driving at the high velocities he had mentioned, which were higher than any cast-iron wheel would stand. Cast-iron rope-wheels were used as far as safety would permit; and beyond their limit the diameter was increased by the use of wheels made with wrought-steel arms and rims, carefully turned and balanced; the result was then most excellent driving.

Mr. Michael Longridge confessed to feeling a certain amount of disappointment after reading the Report; the elegance and

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completeness associated in his mind with the work of French engineers had led him to hope for more information than the Report contained. Presumably M. Dubreuil and his colleagues had carried out the experiments as completely as circumstances permitted; but he could not help thinking that they had gone the wrong way about them. The experiments appeared to have been conducted on what were called practical lines, that is, under ordinary working conditions. Experiments conducted under such conditions were to his mind valuable for proving a particular fact or statement or the fulfilment of a guarantee; but for experimental purposes he was afraid they were generally unfruitful. The conditions which obtained in ordinary practical working were generally not those which were required for purposes of investigation. Where experiments were made under practical conditions it was necessary to have apparatus of large size, such as was used for industrial purposes. It was necessary therefore to have apparatus which was costly, which it was difficult to alter, and which must more or less be worked under the conditions of ordinary practical working. The result of experiments made with such an apparatus was consequently more or less an isolated fact. It exhibited the final resultant of a number of forces, some reinforcing, others tending to neutralise the rest. If any of these forces were to be altered or varied, it would be impossible from the result of the experiment to foresee what the effect of the alteration or variation would be. In fact, the result of an experiment made under what were called practical working conditions, if expressed graphically in the form of a diagram, consisted generally of a single solitary point upon the paper. It was unconnected with anything else, and there was no means of telling in what direction it would move on the diagram, if the conditions were varied under which it was obtained. The experiments at Lille seemed fairly to illustrate this view. In the first place they had evidently been costly; in the second place the cost had evidently militated against variation of the conditions under which they were made; and in the third place they had yielded only a single isolated fact. So far as it went, that fact was valuable of course; but such isolated facts were often used to draw

unwarrantable conclusions. For instance, the conclusion on page 607 he thought was not quite such as could be agreed to unconditionally. It was that, "in the transmission of power, ropes and belts when well arranged absorb almost the same amount of power." No doubt it was qualified by the words "well arranged"; but what did this qualification mean? It seemed to him that it must mean, under the conditions under which these particular experiments were made. Even then however he thought the conclusion could hardly be drawn that under those same conditions ropes and belts would in general absorb almost the same amount of power. Suppose, for instance, that instead of transmitting 160 H.P. it were required to transmit 1,600 H.P., keeping the tensions of the ropes the same—which by the bye were not known—and also keeping the speeds the same; what size of wheels and pulleys would be needed? The belt of 177½ inches width would need a drum nearly 15 feet wide, and the ropes a drum 10 feet wide. The weight of the 15-feet belt drum would considerably exceed the weight of the 10-feet rope drum. Consequently the pressure on the journals with the belt driving would considerably exceed that with the rope driving; and the friction resulting from the pressure on the journals was well known to be a most serious matter indeed. It seemed to him therefore that, by merely increasing the power transmitted, the conclusions arrived at from these experiments were at once upset, although all the other conditions were kept the same. Going further, and supposing the ropes were loaded as they were in Lancashire, namely to 50 per cent. above their load in these experiments, there would then be a belt drum 15 feet wide against a 7-feet rope drum; and the difference in the engine friction between those two drums would amount, he believed, to nearly 30 H.P. Therefore he thought the conclusion that the power absorbed would in general be the same was hardly warranted. Indeed it seemed to him rather curious that the power absorbed should have come out so nearly the same in the two sets of experiments, considering the differences in the frictional resistances overcome. Taking the coefficient of belt friction given in pages 628–9 of the paper, namely 27 per cent., he calculated that the tension on the belts must have been about double the tension on

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the ropes. Consequently the journal friction due to the tension must have been considerably greater with the belts than with the ropes. Then there was no doubt some difference in the resistance of the belts and ropes to bending, though he thought it would not be great. Also there was a resistance which the ropes opposed to coming out of the grooves, but no corresponding resistance in the case of belts. Finally there was the resistance of the air. How was it that all these resistances happened to balance so completely in the Lille experiments? The prior probability that they would not do so suggested the question whether they really did. In their absolute amount it must be remembered that all these resistances were small; in page 627 of the paper it was stated that M. Leloutre's experiment indicated that about 5 per cent. of the whole power exerted was absorbed in overcoming the resistance of belting. The variations to be dealt with were therefore variations of a quantity, which was itself only 5 per cent. of the whole power exerted. For measuring these variations it appeared that indicator diagrams had been taken from the steam engine. It seemed to him rather like cracking a walnut and a filbert under a steam hammer, and taking steam diagrams from the hammer to see which required the greater force. In such a case it would have been better to put the two nuts under a lever and hang weights on the end, and so to find that one would take perhaps 16 ounces and the other 18, whereby it would be seen at once what the true difference was; whereas with the steam-hammer diagrams no difference whatever would be found. Something of this sort he feared was what had occurred in these experiments.

So far as the report went, he thought the choice between ropes and belts would have to be determined on other grounds. General experience, as was well known, showed that there was no great difference between the two. But in matters of convenience there was a considerable difference; and he should like to mention one or two advantages resulting from the use of either ropes or belts. Ropes were attended by what was undoubtedly a great practical advantage, namely a much narrower and lighter drum. They also possessed another great advantage in the facility they afforded of driving on the skew, which could not be done with

a belt without guide pulleys. With ropes two shafts could be driven with great ease when inclined to each other at an angle of about seven degrees; and Mr. Barbour of Belfast, whose firm originated rope driving in this country, had recently informed him, when he was making enquiries on the subject, that even with tolerably large drums there were no serious difficulties in driving two shafts inclined at even fourteen degrees. Then there was the further advantage that the ropes could be put on and taken off one at a time, and thus a faulty rope could be changed without having to stop the machinery. It was said that, if this were done, the difference in diameters of the ropes—the new rope just added, and the old ropes which still continued running—caused a great loss of power. He did not believe that to be the case, and he did not see why it should be so; at all events he did not see why more power should be lost from using conjointly ropes of rather different diameters than was lost by working a belt over a crown pulley. In the latter instance there were the two different diameters—the larger diameter in the middle of the pulley, and the smaller diameter at the two sides; and the difference between these two diameters was greater than the difference in the effective diameter in the grooves of a rope drum with ropes of slightly different size. Then again the ropes ran under a lighter tension, which was certainly a great advantage. Another advantage too in favour of ropes was that they would stand in some positions where leather belts would not stand: for instance, where there was a good deal of heat. On the other hand, he believed ropes were more costly and more troublesome to keep in repair. They required more looking after than belts, and they could not be worked with jockey pulleys as belts could, because the bending in the two opposite directions destroyed them so rapidly.

These were the chief advantages and disadvantages of the two plans; and the conclusion he came to from them was that, for heavy driving and long distances, ropes were undoubtedly preferable; but with light driving, and where the distances were short, belts were equally good, and less trouble to keep in order, though more expensive in first cost.

The President asked if Mr. Longridge could give his views as to the length of drive for ropes and belts respectively, in relation to the comparative sizes of the driving drum and the driven pulley.

Mr. Longridge knew an instance of a drum 17 feet diameter driving by ropes a pulley of 9½ feet diameter, with a distance of only 7 inches between their rims. In another instance a 13-ft. drum was driving by ropes a 7½ ft.-pulley, and the distance between their rims was only 9 inches. In a third instance, where the ropes had now been on for about eight years, there was a 17-ft. drum and a 7½-ft. pulley, and their centres were 15 feet apart; that would leave 2 ft. 9 ins. between their rims. These were all short drives for ropes; and there was no difficulty with short drives for ropes, provided enough ropes were put upon the driven pulley. With a given driving drum, the arc of contact on the driven pulley became less as its diameter was diminished, and as the distance apart became less; more ropes were then required. With belts he did not know that there was any limit to the closeness of the drums; by the use of jockey pulleys the drums could be put as close to each other as might be desired.

Mr. Bryan Donkin, Member of Council, believed that rope driving, which Mr. Longridge had mentioned as having been originated in Belfast (page 635), had previously been introduced in Alsace in 1852 by Mr. C. F. Hirn of Colmar with ropes of steel wire.* It seemed to him a great pity that the programme of the Lille experiments, which he had received an invitation to attend, had been so limited as the Report showed. The best thanks of engineers were nevertheless due to M. Dujardin for the great trouble and expense he had incurred, and to M. Dubreuil for the opportunity afforded for Professor Capper to be present. It seemed that the practical results for the set of five horizontal ropes, and for the one cotton or the one leather belt working horizontally, were almost the same, as far as the friction was concerned; but this was

* Notice sur la Transmission Télodynamique, par C. F. Hirn; Mulhouse 1867.

only at the particular speeds and under the particular conditions of the experiment; and he quite agreed with Mr. Longridge that it must not be inferred that the results would be the same under conditions different from those of the experiments and at different speeds. From Table 13 the ropes seemed to have given less than half the slip of the belts; but from pages 624–5 there appeared to be some doubt on this point. There was the same linear speed in each case, and the same tension per square inch of section. He asked whether the ropes and belts were new at the time of the experiments, and whether they were unusually tight or not. He should also be glad to know the cost of the ropes and belts; and a further question suggested by Mr. Longridge's remarks was the weights of the fly-wheels and pulleys. The interesting summary of previous experiments, given at the end of Professor Capper's paper, he thought would be found highly useful.

Mr. Alfred Saxon agreed with Mr. Longridge in fearing that for practical purposes these experiments were of doubtful value. That the resolution decided upon in page 600 should have been adhered to through thick and thin, was perhaps rather unfortunate. In the first instance an offer seemed to have been received of an engine of 200 H.P., and then the number of ropes seemed to have been decided upon that would transmit the 200 H.P. at a given speed; and he supposed the width of belt as well. These decisions he presumed had been based on calculations. If so, it would seem that the number of ropes adopted had no doubt been determined on the basis of transmitting about 40 H.P. per rope, so that the five should together be equal to the 200 H.P. which the engine was supposed to develop. But from Table 13 it appeared that, when the experiments came to be carried out, the engine actually developed only about 160 H.P. It would therefore have been an easy matter he thought to take one rope off, when it was found the engine was developing only 160 H.P.; and the four ropes might then have transmitted the 160 H.P. without any more slip than the five did, provided the four had not been working above their calculated power. It was also unfortunate he thought that no other kinds

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of ropes had been tried in addition to manila hemp ropes. In Lancashire he knew of only one large mill, driving about 1,000 I.H.P., which used manila ropes; but that was an exception. The rule in Lancashire certainly was for cotton ropes to be used; and as a cotton belt had been found to test against the leather belts in the Lille experiments, he should have expected that cotton ropes would also have been found to test against the manila ropes. Great care he thought had been taken in connection with these experiments, so far as they had gone; the results were indeed so uniform, that it seemed to him, as it apparently did to Mr. Longridge also, that they were almost too uniform.

In the comparison of expense between belt driving and rope driving, his experience differed from that of Mr. Longridge in the matter of repairs. An engine with a 28-foot drum and with three belts, each 30 inches wide, had been supplied by his firm to drive about 800 H.P. Those belts had been rather more expensive to maintain than rope driving which had been supplied to other similar works; and his own opinion was that belts of a large size were more expensive than rope driving. Under most circumstances he certainly agreed with Mr. Longridge that rope driving was considerably more favourable than belt driving. For transmitting the same power a rope drum was considerably narrower than a belt drum; in these experiments the rope drum was 13 inches wide and the belt drum 18½ inches wide (page 623). This was a point which had had to be carefully borne in mind in transmitting large powers; and at the present time most Lancashire engineers would certainly go in for rope driving for large powers, in preference to belt driving, on account of the difficulty of supporting the wider belt-drum without deflection of the crank-shaft in working. During the period that rope and belt driving had been in use, several serious breakdowns had occurred, owing to the length and weakness of the crank-shafts and their consequent deflection; in many instances the constant heavy friction on the journals and frequent heated necks had caused the bearings to give way. In these experiments it appeared from page 606 that each belt was tightened up by adjusting screws to the particular tension which its maker thought best for

it to work at. The ropes however were not touched; they were simply applied, and, whether they were applied rightly or wrongly, the tension gear was not used with them. What could be done in the driving of a large mill, if it were necessary to have an adjustment for the belts in every storey? With rope driving the requisite tension was obtained without adjustment; and in these particular experiments the ropes seemed to have been put on sufficiently tight to do without any use at all of the tension gear.

The rope speed used during these trials seemed to him to be what was agreed upon by the committee as producing the best results for all diameters of ropes. Speeds of from 4,750 to 5,000 feet per minute were generally considered to produce the best results with ropes; and although Mr. Platt had referred to 6,000 feet per minute as having been tried some years ago (page 631), there were few engineers now, he believed, who would think of going beyond 5,000 feet per minute. In connection with rope-driving in Lancashire the sizes of the ropes used were being diminished, and a greater number of ropes used, in preference to a smaller number of larger ropes. For so small a power as only 160 H.P. the ropes of $1\frac{3}{4}$ inches diameter used in these experiments seemed to him to be rather too large; the ordinary Lancashire practice at the present time would be to use $1\frac{1}{2}$ inch ropes for such a power. If time had permitted in the experiments, varying speeds and varying width of belts and varying number of ropes, and a number of other variations, might have been usefully tried.

The mode of determining the slip in the Lille experiments had not been stated in the Report. The thanks of mechanical engineers were due, he was sure, to their French brethren for their trouble in this matter. While all would be sorry that the experiments had not been extended further, it must be borne in mind that the expense of extending them would have been so great. Personally he desired to thank Professor Capper for the careful way in which he had placed this subject before the Institution.

Mr. Druitt Halpin thought it was a great pity that these experiments had not been so carried out as to bring to light what

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was wanted to be known, instead of what was not wanted. It need not in his opinion have necessarily cost £6,000 (page 601) to determine the friction and the absolute power absorbed by the ropes and belts, which was what engineers wanted to know. Starting at one end with indicator diagrams taken from the engine, these seemed to have been made use of without any account being taken of what the friction of the engine was. The driving was then done through the ropes and belts; and at the other end an electrical measurement was obtained, for whatever it might be worth. This final standard indeed seemed to him to be altogether on so untrustworthy a scale that he thought it could not be relied on. The indicators could be calibrated, as had been done, so as to know what was being done at the engine; but what was being done at the other end was in his opinion a matter of great doubt. If it had merely been intended to find what was the power absorbed by the ropes and belts, he thought it might have been done at a reasonable expense in the way hinted at by Mr. Longridge (page 634). If the driving pulley or fly-wheel had simply been made perfectly loose on the driving shaft, and the driven pulley also loose on the driven shaft; and if on the driven shaft had been put any work or resistance whatsoever—a centrifugal pump or a dynamo or anything else—to take up the power, whatever the amount of the power might happen to be; and if also a spider or drag-link had been fixed on each of the two pulleys, and connected with the pulleys by dynamometer springs:—then autographic diagrams could have been obtained, recording exactly what power was being put into the driving pulley, apart from what was being lost in engine friction, and also recording exactly what power was being given out by the driven pulley for performing the work. The difference between the two amounts of power thus recorded would be the power absorbed in transmission by the ropes or belts. In that way the data wanted would have been directly arrived at; and he thought the expense of making the requisite apparatus of the kind he had indicated would not have been anything considerable. Apart from the dynamometer springs, the whole of the rest of the gear was common everyday work; and the ordinary pulleys could have been used, without having necessarily to be charged to the job.

Mr. W. Worby Beaumont thought that perhaps the criticisms already offered in the discussion as far as it had gone might suggest to Professor Capper the desirability of reviewing the figures he had given, and perhaps of adding to the value of his paper by giving some further results of the experiments. He noticed that all the belts and ropes used in the Lille experiments were presumably new, having been specially ordered (page 600) for these trials. It seemed to him a pity that some belts and ropes had not been tried which were not new, particularly belts; because it was well known that there was a great deal of difference between the losses in belt driving with old and with new belts; the grip of the pulleys by old belts was much higher for a given tension, and the journal friction correspondingly less for the same driving pull. His own observations had shown that the losses attendant upon the use of tight belts and bright pulleys were generally much under-rated. Moreover, although the tension upon the ropes and belts was given in Table 13, it was not stated how that tension was ascertained; it was only mentioned (page 606) that during the experiments with the belts the tension was regulated by the makers of the several belts, until they got whatever they considered to be the best for their own particular belts under the particular load they were working at, which was practically about the same in all the trials. Considering that there had been those facilities for varying the belt tensions, he thought it might naturally be expected that the results of all the experiments would come out pretty much the same. There would be a similar amount of bearing friction; and the losses due to bending and unbending of the belts, and to adhesion of the ropes in the grooves, would leave the amount of work to be done in each case very much the same. Hence in percentage the losses could in fact vary but little. Of the surface of the belt pulleys no mention had been made, as to whether it was highly polished or only rough turned; but its condition made a great deal of difference. The machinery at disposal for these trials he thought would rather have warranted some experiments at no great extra cost, which would have added to present knowledge, more particularly as to the amount of power absorbed or lost in these two methods of driving.

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The Report had certainly not given much new information; and perhaps Professor Capper might be able to add thereto from his own observations.

Mr. E. Tremlett Carter suggested driving the rope or belt gear, not by a steam engine, but by two equal dynamos, as in Dr. Hopkinson's method of testing dynamos, driving one as a dynamo and the other as a motor, somewhat on the plan mentioned by Professor Capper in page 622. With the two directly coupled, their combined mechanical efficiency could be ascertained; and from their combined efficiency it could be ascertained what would be the efficiency of each separately. On then separating the two dynamos, and making one drive the other through the rope or belt gear, from the new efficiency would be ascertained the difference which would be due to the intervention of the ropes or belt. On now taking off the ropes or belt and driving the dynamos with only the pulleys on, making the one drive the other electrically as a motor, the amount of extra bearing friction which was due to the weight of the pulleys would be ascertained. In this way three efficiencies would be obtained: firstly, the efficiency of the dynamo and motor by themselves; secondly, their efficiency when geared together by the ropes or belt; and thirdly, their efficiency when they were loaded only with the rope or belt pulleys. From those three efficiencies, and from the known electrical power supplied to the motor, might be deduced the loss of power due to the flexible connecting link, and the loss due to the friction of the pulley bearings. From his own calculations and experience he had found that the limit which determined the choice between belts and ropes was about 100 H.P.; below this power it was better to use belts, and above it ropes were preferable, as a rule. An instance of the difference had been met with in the early days of electric lighting, which happily was not met with now, where it had been necessary to develop a considerable amount of power from a dynamo running at a considerable speed. It had then been requisite to have a pulley of small diameter on the dynamo; and as ropes were injured by having to pass round such small pulleys, it had been preferable to use a thin belt.

Mr. R. E. B. Crompton considered Mr. Carter had pointed out what was undoubtedly a very accurate way of carrying out the test in a practical manner; and it ought to have been so carried out long ago. To call that method Dr. Hopkinson's however was a mistake that was often made. Dr. Hopkinson's method consisted in obtaining the efficiency of two dynamos by driving them coupled together in such a manner that the power wasted in the two had only to be supplied by mechanical means; and the power was measured also by mechanical means by a brake. It was a method which had been a great advance on anything that had ever been carried out before; but it was not by any means perfect, and it had now been superseded by a method, devised almost simultaneously by three persons—Lord Rayleigh, Mr. Swinburne, and himself—of supplying by electricity the balance of power required to drive the two dynamos, and consequently making all the measurements by electrical means. In spite of the doubt implied in a previous speaker's remarks (page 640), electrical measurements of power might be now taken within such a percentage of accuracy that no mechanical measurements of power could be compared with them; and these electrical measurements gave such facilities that, if a series of experiments were carried out in the way proposed by Mr. Carter (page 642), data could be obtained which would be of the greatest value. Experiments and measurements of that kind were now carried out daily in many electrical engineering workshops. In carrying out the above method of testing, it was frequently the case that the dynamos could not be coupled end to end, and that it was necessary to couple them mechanically by ropes or belts, so that the friction due to side pressure on the bearings came into play; and although no careful experiments had yet been carried out, he believed it was well known to most makers of dynamos and motors that, where they had to use these means of driving, either by belts or ropes, which involved side pressure on the bearings, the power thus lost amounted to not less than from 7 to 9 per cent. This was more than double the 3 to 4 per cent. mentioned in page 629 as the total loss in well-designed belt gearing. In looking through the Report he was indeed much disappointed to find that the question of the actual

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efficiency of the transmission was nowhere entertained. With the exception of the $68\frac{1}{2}$ per cent. given by Professor Capper (page 623) as the combined efficiency of the whole system, he had really been unable to find anything at all about the efficiency, which was a most important and interesting feature for all engineers. A good deal had been said about slip, and about the power of certain belts to resist tension; but he could not find any attempt to analyse the total loss due to the transmission, that is, the total loss between the indicator diagrams and the measured electrical horse-power. While he agreed with Mr. Halpin (page 640) that the indicated horse-power had probably been obtained fairly correctly from the indicator diagrams, he also thought it was clear that the electrical horse-power had been ascertained fairly correctly, so that the above combined efficiency of $68\frac{1}{2}$ per cent. was probably nearly correct. Another measurement which would have been interesting, and might have been obtained, would have been that of the dynamo efficiency. The Alsatian Company, who had furnished the 200-H.P. dynamo (page 601), had certainly not constructed a dynamo of that size which could lose so much as 10 per cent. in heating up its coils, for power so wasted would soon burn them up. But even if so low an efficiency as 90 per cent. for the dynamo were adopted, and 85 per cent. for the ratio of the brake horse-power to the indicated horse-power of the fine engine used, the conclusion was inevitable that the loss in the belt as well as the rope transmission was 10 per cent. or thereabouts. Thus, indicated horse-power 100, brake horse-power 85, at pulley of dynamo after rope losses 76, and at terminals after 10 per cent. dynamo loss $68\frac{1}{2}$. These figures, which he had worked out from the Report, he thought were fairly correct; and they agreed fairly well with the experience of most of the electrical engineers who had been transmitting large amounts of power by means of belt and rope driving for many years past. But to electrical engineers indeed the transmission of power by rope and belt driving possessed a different kind of interest. As regarded their generating plant the day for ropes and belts had gone by, since the advent of high-speed engines had enabled dynamos to be driven direct; and they most of them thought that a few years hence would see all machinery

driven direct by electricity, and that belting and shafting would become curiosities of the past. Hence electrical engineers were not now so interested as formerly in the efficiency of mechanical transmission of this kind. A few days ago he had been in Cornwall, the land of flat rods and fend-off bobs, as they were called; and with the efficiency of that mode of transmission the people there seemed well content. Having worked out a few of their efficiencies for his own benefit, he had found that a very small percentage of the indicated power of the engines was being really utilized by the pumps at a distance in some cases of only 100 and even only 50 yards from the engines. As therefore he looked upon Cornwall and similar mining districts as offering a splendid field for the introduction of better modes of transmitting power, so he thought electrical engineers would a few years hence look upon all modes of rope and belt transmission as presenting an equally happy opportunity for the substitution of that silent, steady, and infinitely flexible connecting-rod which was called electricity.

Mr. William Geipel thought the method suggested by Mr. Carter (page 642) for measuring the efficiency of the rope or belt transmission would not give its efficiency at full load, that is at full tension, which he believed had been the object of these experiments. Steadiness of rope driving had been referred to by Mr. Platt (page 631) as due to high speed; and his own experience was that the steadiness did not depend on the speed alone, but also on the length of the drive. In some cases he had had to shorten the drive in order to cure the swaying and riding of the ropes. The difficulty mentioned by Mr. Platt (page 631) of getting governors to run steadily when driven by belts, instead of being direct driven, was one which he had not himself experienced. A direct driven governor he admitted was safer and more certain in some respects; but it often produced considerable extra expense in an engine, and it also rendered the engine much more difficult to adjust to its right speed. The jumping of the laced joint over the pulleys he supposed was what constituted Mr. Platt's objection to driving a governor by a belt; but with a properly laced joint he thought there should be little

(Mr. William Geipel.)

variation in the speed; and that little, it appeared to him, might often be an advantage in governing, for it might give the governor just the slight impetus or shake which would enable it to adjust itself to the new conditions of work.

In driving by belts in these experiments he thought it was somewhat important to know what was the amount of camber or convexity in the rim of the belt drums. If there was too much camber it would conduce to extra slip, owing to the difference in speed between the centre of the rim and its two edges. In the examples given by Mr. Longridge of short driving with ropes (page 636) he noticed that the greatest difference between the diameters of the two pulleys did not exceed 2·3 to 1; and he should like to know whether there had been any experience of short driving with ropes where the ratio was as much as 6 to 1, because in many industries one of the great reasons now for using belts or ropes was to adapt a slow-running motor to a quick-running machine. For the high speed of 6,000 feet per minute, mentioned by Mr. Platt for rope driving (page 631), he should be glad to know what sort of fly-wheels and pulleys had been used, because he believed this was considered to be the ultimate safe speed at which a cast-iron pulley should run. There did not seem to be any margin then left for a temporary increase in the speed of the pulleys, such as might occur if any part of the apparatus failed: in which case the increase of speed might jeopardise the whole of the precincts.

Mr. Michael Longridge replied that there were plenty of instances where the ratio of pulleys used for rope driving was 6 to 1, but of course in all these there was a longer distance between their centres. It was a common thing in rope driving to run the main shaft of a spinning mill at 270 and even 300 revolutions per minute, and the engines from 55 to 60. Naturally it was impossible to get a high ratio with a short drive, except by having a large number of ropes; it was only a question of the number of ropes.

Mr. E. Tremlett Carter trusted no one would be deterred from an experiment because of any misapprehension arising from

Mr. Geipel's remark (page 645) as to being unable to measure the efficiency of rope or belt transmission at full load by the electrical method he had proposed. For supposing in a given arrangement on that method the efficiency could be measured only under half load, it was evident that there would then be too many ropes, and half the number should be taken off; or, if a belt was being used, a narrower belt should be substituted. If there were 100 H.P. going mechanically between two dynamos, such a size of pulleys or such a number of ropes or such a width of belt should be used as would correspond with the mechanical power passing by the ropes or belt between the two dynamos. In that way it was quite possible to measure the ropes or belt under the same conditions of sag and strain and speed as in the Lille experiments or in any factory; and he trusted it would be done. It might be doubted whether the amount of wasted power in rope or belt gear was really different at different loads; in all probability the loss of power in the gear was the same absolute amount, he thought, at all loads.

Mr. H. Sherley-Price asked whether the fly-wheels and pulleys used in the Lille experiments had been properly balanced. If they were not completely balanced, jumping would probably have been produced to some extent, which might have affected the slip and the loss of power in transmission. He remembered many years ago in Yorkshire a mill was nearly pulled down by a large unbalanced belt-wheel running at a speed of about 4,000 feet per minute. The wheel was mounted just outside the end of the mill, and high up; and was so badly balanced that cracks developed in the end walls of the mill, and the mill became so shaky that it had to be rebuilt at that end.

Mr. William Schönheyder asked whether the shape of the rim of the belt fly-wheel used in the experiments was elliptical or circular. It was referred to in page 606 of the Report as Messrs. Van den Kerkove's form; and he should be glad to know what they had found to be the best shape.

The President said that Mr. Robert Goodbody, of Clashawaun Jute Factory, Clara, Ireland, and Mr. A. Basil Wilson, of Belfast, being unable to come to the meeting, had communicated their views in letters which would now be read.

Mr. Robert Goodbody wrote that he did not consider the Lille installation had been erected in such a manner as English experience had proved necessary. To put ropes of $1\frac{3}{4}$ inch diameter upon a drum of only 58 inches diameter was out of the question, if durability was expected of the ropes; the drum should have been nearer 88 inches diameter. The ropes he also expected had been too large for the grooves; his own experience had proved that ropes should run in their grooves almost touching the bottom. He had himself ropes of $1\frac{1}{2}$ inch diameter running fifteen years without being taken off, working in grooves originally made for $1\frac{3}{4}$ inch ropes. Also similar ropes running 4,000 feet per minute, giving off 40 to 43 indicated horse-power constantly for 56 hours weekly, he had found to run about eight years, without being re-spliced from the time of being put on.

Mr. A. Basil Wilson wrote that he feared the Lille experiments were by no means final. His own experience had been that ropes absorbed some 6 per cent. of the power per transmission, and belts $2\frac{1}{2}$ per cent.; the greater loss with ropes arose from the difficulty in practice of keeping the diameters of the ropes and consequently their effective pitch-line constant. It was thus a matter seriously affecting mill-owners everywhere.

Professor Capper said most of the criticisms that had been offered were in such a form as not to require any answer from himself, having been simply directed towards the methods in which the Lille experiments had been carried out, for which he was not responsible.

The shape of the Van den Kerkove rim of the belt fly-wheel (pages 646 and 647) was cylindrical in the centre for about one-fifth of the whole breadth of $18\frac{1}{2}$ inches, Fig. 4, Plate 151, and the outside

tapered down conically to each edge, the radius at the edges being 0·18 inch less than in the centre; in the pulley the difference of radius at the centre and at the edges was only about half as much. So far as he knew, the rope and belt fly-wheels had not been specially balanced for the experiments (page 647), but there had been no evidence of any unequal rotation. He could not agree with the suggestion (page 645–6) that the jump of the laced joint of a belt round a governor pulley was in any way an advantage; he should certainly have thought that by this time it would have been generally found that it did not conduce to the good working of the governor.

The efficiency of 68½ per cent., given in page 623 as the total efficiency, was measured on volt and ampère meters, which had not been calibrated. He had therefore been obliged to avoid going into the question of the efficiency of the various portions of the transmission, because uncalibrated meters could not be reckoned upon within a margin of 5 or 6 per cent. at least, and consequently any deductions were to that extent inaccurate. In matters of this kind of course he had been entirely dependent upon what he had been enabled to ascertain; and where there had been omissions of this sort in the conduct of the experiments, he could simply say that the information was not forthcoming. The method proposed by Mr. Carter (page 642) had been referred to as a suggestion offered by M. Neu (page 622), which had been considered impracticable owing to the extent and cost of the apparatus it would involve.

The condition of the surface of the belt pulleys (page 641) was as they had left the tool, smooth turned, but with the tool-marks upon them; they had not been specially polished. As regarded the results of the experiments, there were not any further figures which he could add (page 641), because every figure that he had been able to obtain was embodied in the paper; there was no information he possessed which was not contained in the paper. It was the review of previous experiments, given in pages 625–8, which he had referred to as not an exhaustive summary (page 630), because he had not extended it so as to include all the experiments which he knew had been carried out, but had referred only to those which he thought were of practical importance to the particular purpose of the paper.

(Professor Capper.)

The suggestions made by Mr. Halpin (page 640) were of an excellent and practical character; and he agreed with him in wishing that dynamometers could have been used in the way he had indicated. If that could have been done, he should certainly have urged it.

For the determination of the slip (page 639) the whole period of the run had been included, and the mean speed of revolution of both the fly-wheel and the pulley had been reckoned on the total run, and the slip had been determined from the difference of the corresponding circumferential speeds. From the information given by Mr. Saxon (page 639) about the proper speeds for belts and ropes he was glad to think that the speeds employed in the experiments were about right.

The ropes and belts used in the experiments (page 637) were all new, as rightly surmised by Mr. Beaumont (page 641); and that was one of the reasons why there had been a preliminary run to commence with on the morning of the first day, in order to get them into working condition. Naturally they were not even then in the condition they would have been in after weeks and months of wear. If it had been possible to vary the kind of belt in regard to its newness or oldness, of course a good deal of additional information might have been obtained, which would have been of great value.

He desired to thank Mr. Longridge for his extremely interesting observations (pages 632–6), in which he had given so considerable an amount of information. Personally he was himself largely in accord with him in the remarks he had made about the experiments, though he appreciated to the full the courtesy with which the French engineers had treated the Institution, and was indebted to them for the information which these experiments had furnished.

The President was sure the Members would join in giving Professor Capper a hearty vote of thanks for having gone over to Lille to witness these experiments on behalf of the Institution, for having translated the Report of the Commission, and for having afterwards recorded his own observations, pointing out some of the leading results obtained. He knew that no one regretted more than

the author himself that the experiments had been so obviously incomplete. The results must be taken for what they were worth; and the Members were glad to get them, because they certainly did represent, as Mr. Longridge had remarked, a particular fact upon a large scale; and perhaps still more because they represented a notable act of what might be called "scientific courtesy" on the part of their continental professional brethren. He was sorry to have received a telegram from M. Dubreuil, the President of the Commission, stating that he was detained in Paris by illness, and therefore not able to be present. Otherwise perhaps he might have been able to give some of the reasons which had influenced his Committee, after taking so much trouble, in stopping short of carrying the experiments to a point which would have given a great deal more information.

With regard to Professor Capper's estimate of the efficiency (page 623) as measured on the volt and ampère meters, he gathered from page 602 that the voltmeter at least had been carefully calibrated.

Professor Capper explained that the torsion voltmeter, mentioned in page 602 as having been carefully calibrated, was the instrument by which the potential difference was measured in M. Dujardin's office, and gave readings only in arbitrary units, for which the constant had not been determined. The voltmeter from which the electrical horse-power had been estimated was at the dynamo, and was therefore at some distance from the point on the main conductors to which the torsion-voltmeter leads were attached.

The President thought under those circumstances there was certainly some ground for Mr. Halpin's strictures upon electrical measurements (page 640), so far as these particular experiments were concerned. At the same time he was confident that mechanical engineers, of whom so many had experienced, like himself, the perplexing difficulty and the harassing anxiety of calibrating indicators and dynamometers for such a use as had been suggested by Mr. Halpin (page 640), would be the last to disparage electrical

(The President.)
measurements. For he need hardly point out that there was absolutely not the slightest difficulty in making these measurements with a degree of accuracy with which the best calibrated indicator was not to be compared. It was certainly unfortunate therefore that uncalibrated instruments should have been used, which involved the possibility of errors of 5 or 6 per cent. (page 649).

As to the absolute loss of power in transmission by ropes or belts, which it was so difficult to get at, he should indeed have been glad if some information had been forthcoming of a more positive character. It had been concluded by Mr. Crompton (page 644) that the loss must be 10 per cent. of the maximum power of the engine. Somewhat imperfect experiments of his own had not pointed to so high a proportion, but to somewhere between 5 and 10 per cent. During the few remaining years which, according to Mr. Crompton, were to be allowed by electrical engineers for rope or belt transmissions to continue in use by the benighted people in Lancashire and elsewhere, it was really important to know how much was wasted by it. As soon as they did know how much was wasted by it, he was sure they would cease to use it; because it should be remembered that, inasmuch as at full load the loss was more likely 10 per cent. than 5 per cent., it would probably rise to 15 per cent. when the engine was running at from half to three-quarters load, as so often happened.

Mr. Michael Longridge interposed that it rarely happened in Lancashire that mill engines ran much below their full load.

The President said he had often tried to find out beforehand the amount of power that would be required in a factory or works, but had never succeeded in doing so to the extent implied by Mr. Longridge's remark. He was delighted to hear that in Lancashire they knew so exactly beforehand the power which would actually be used in a factory—as distinct, of course, from the maximum power which might possibly be sometimes required—that they could put up an engine of just the power required, and so be able always to work it at full power. Engineers who lived further

south had not yet reached that point; and it therefore often happened that their engines ran at only between 70 and 80 per cent. of full load: 75 per cent. was good, if it could be got. Consequently the loss in transmission was increased considerably in proportion, and came to mean probably a waste of 15 per cent. of the whole coal used in the factory, for the mere pleasure of driving round those elegant lines of leather, hemp, or cotton, in regard to whose behaviour there was at present such a dearth of any definite information.

Dr. William Anderson, C.B., Past-President, wrote that he had been rather disappointed with the Report of the Lille experiments on power transmission by ropes and belts. The nature of the resistance selected had practically confined the trials to one speed, so that no data had been obtained at various velocities of ropes and belts. He particularly regretted he had been unable to attend the discussion of this subject, inasmuch as one of the last announcements he had had the pleasure of making, on retiring from the Presidency of the Institution, had been that of the welcome invitation received from Lille, and of the appointment of Professor Capper to represent the Institution at these experiments (Proceedings 1894, page 23). Other opportunities he hoped might arise in future for co-operating in similar trials.

Mr. Charles Hopkinson wrote that it was to be regretted so little could be learnt from such elaborate and expensive experiments. In order to be truly instructive, the experiments should have been arranged for more than the two variable elements, namely the material of the connecting band and its contact with the pulleys. The elements which in well arranged experimental machinery might have been known variables would include, for example, the initial tension of the bands, so as to demonstrate the effect of tension in regard to losses of work, and thereby to afford some guide to the relation between aerial friction, journal friction, and resistance to bending. The method suggested in page 622 of the paper—a motor dynamo driving a generator dynamo, directly or by band—would

(Mr. Charles Hopkinson.)
have afforded facilities for a series of experiments, in which the loss due to variations in initial tension, in shape of contacts, in number of ropes or width of belt, in band speed, in diameter of pulleys, in band load, and in band length, could have been determined with such accuracy as would have afforded a suitable basis for checking theoretical conclusions. In a series of experiments on belt driving, in which the writer is determining the slip with varying conditions of tension in the two sides of the belt, he has thus far not recorded, when driving a sensible load, any slip so low as those in Table 13; with overloaded belts he has recorded a slip of 5 per cent. and upwards. The belts tested have been plain leather, link leather, and Reddaway "camel" belts.

M. L. Neu, of Lille, who regretted that he was unable to come to the meeting, wrote that at the time of the rope and belt trials he had urged the importance of ascertaining the degree of accuracy of the measuring apparatus. The accuracy of the electrical apparatus being easily ascertained, it remained only to determine the sensitiveness of the indicator diagrams which formed the basis of the comparative measurements. For this purpose he had asked that a series of diagrams should be taken under loads continually decreasing by a small amount, such as the successive extinction of the lamps in groups of eight or ten. It would thus have been easy to see how soon this variation of load became perceptible in the diagram; and the degree of accuracy would thus have been known with which a diagram admitted of calculating the load on an engine. At present he thought this was but little known. Unfortunately his request had not been acted upon; and he took exception to the Lille trials as being measurement tests made without knowing beforehand the sensitiveness of the means employed. It seemed rather like a chemist wishing to make a quantitative analysis, without knowing the sensitiveness of the balance he used.

M. V. Dubreuil wrote that the Société Industrielle du Nord de la France, on the proposal of their civil engineering committee, had agreed that the experiments which were to be made on the power

absorbed by ropes and belts should be carried out under their auspices, on condition that the tests should be conducted with every possible guarantee, and should be under the supervision not only of members of the Society, but also of any foreign engineers who might desire to take part in them. With this object the engineering committee appointed a Commission of competent engineers, who, inasmuch as the experiments would be of so distinctly general a character, decided that they could not, in the limited time they could devote to the trials, deal with all the questions of the problem to the same extent that could be done by an individual experimenter. They were also of opinion that the number of engineers invited to attend from France, Alsace, England, and Belgium, rendered it necessary that the work should be carried out concisely and quickly. Knowing that, except at the risk of excessive fatigue and consequent errors, as much cannot be expected from a number of observers as any one by himself might be willing to do, the President of the Commission limited the programme to a field of action which would have become confused if it had been more varied. The longer the duration of trials of this kind, the more liable to variation is the performance of the mechanism, while at the same time the greater is the amount of trouble entailed upon the professional assistance of any one who, like M. Dujardin, had so obligingly offered the use of his works for the experiments. For these reasons the trials were necessarily limited. After the hemp ropes, experiments might indeed have been made with cotton ropes, square ropes on the Swiss plan, india-rubber and camel-hair belts, thong or link belts, the ropes small or large, and the belts single, double, or three-ply; and these might have been driven at speeds varying from 2,000 to 8,000 feet per minute, running horizontally, obliquely, or vertically. But all this would unfortunately have introduced confusion and inaccuracy. On the whole therefore the Commission agreed with the Société Industrielle in desiring to produce a positive record, for which they could be responsible. This record has been produced, and as a record it is as accurate as possible; and the Société Industrielle would be glad if, now that this landmark has been set up, other societies would kindly take up these experiments

(M. V. Dubreuil.)
and complete them. The Société Industrielle wished these tests to be carried out under the practical conditions of good machinery.. With this aim the Commission took as a basis the speeds and other data obtained as an average from more than 100,000 horse-power of good machinery; and the dimensions of the belt fly-wheel and the number of grooves in the rope fly-wheel were specially arranged for the power which the dynamo would require, irrespective of the power that could be given out by the engine. The aim having been to give the experiments a comprehensive character and to approximate as closely as possible to the practical conditions of rope and belt driving, in the writer's opinion the calibration of the voltmeter on the dynamo did not matter, inasmuch as the Siemens and Halske torsion voltmeter and the Wiedemann and d'Arsonval galvanometer (page 602) furnished an exact measure of the resistance, while the efficiency of the dynamo did not enter into the question. As to the accuracy of indicator diagrams, this was a point which had not been gone into, because so much depended not only on the skill of the observers and the accuracy of the instruments, but also on the variations in the mechanical efficiency of the engine at different loads. Such an investigation was seen to be of too delicate a nature; and though everyone agreed in reality with M. Neu, it was decided to adhere to the ordinary methods of investigation. The sole object of these remarks, which the writer has the honour to present in the name of the Société Industrielle, is to show the great interest attaching to questions of motive power. They afford him at the same time the opportunity of offering to the Institution of Mechanical Engineers, and especially to Professor Capper and to those members who have been so good as to study the Report, the thanks of the Société Industrielle, with his own, for the care, attention, and courtesy with which they have dealt with this work.

Professor Capper wrote that, in order to avoid any misapprehension, he wished to explain that the scheme of the experiments professedly left out of account the absolute determination of the power absorbed. As therefore only a relative

determination was required, it was thought by those responsible for the arrangements that it was sufficient to determine the potential difference in arbitrary units only. If these were kept constant, it was considered that the resistance would remain constant throughout the experiments. The only definite measurement of voltage was therefore made by an uncalibrated voltmeter; and in his observations (page 623) he had given the efficiency of $68\frac{1}{2}$ per cent., as determined by its readings, for what it was worth.

ABSTRACT OF REPORT ON THE RESULTS OF PRELIMINARY TESTS OF THE STRENGTH OF COPPER.

By Professor A. MARTENS,
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Translated and Abstracted by Mr. C. H. Moberly.

The available data respecting the properties of Copper, especially in various states of hardness and at various temperatures, are very conflicting. Many authorities put the ultimate tensile strength at 15 tons per square inch, and the safe working stress at 3 to $3\frac{1}{4}$ tons, whilst for copper drying cylinders some give 1·6 ton per square inch as the greatest safe working stress. Reuleaux gives the ultimate strength of hammered copper as 19 tons, and Renier as 19·7 tons; whilst Fremery gives that of rolled copper plates at 15 tons and Navier at 12 tons per square inch. Three tables of results of tests are given on page 659 to illustrate the discrepancies of data.

To remedy this state of uncertainty, in 1890 the Minister of Commerce and Industries, after correspondence with the Steam Boiler Inspection Societies and with the approval of the Royal Technical Deputation for Commerce and Industries, gave instructions for carrying out a full investigation of the properties of copper. A very complete scheme was prepared for carrying out the whole of the experiments contemplated; but it was not possible to carry out this scheme in the order contemplated, and the Report follows the actual order in which the work was done.

In these investigations special difficulties arise in connection with:—the variable admixture of foreign substances in the copper of commerce; the influence which the method of working the copper has on its properties; and the influence which the method of conducting the experiments has on the results.

TABLE 1.

Condition of Material.	Stress in tons per square inch. Elastic limit. σ_S	Ultimate stress. σ_B	Ratio. $\frac{\sigma_S}{\sigma_B}$
Not Hammered, nor Brazed	4·1	13·3	0·31
Lightly ,, not ,,	6·6	15·5	0·42
,, ,, and ,,	6·5	14·0	0·46
Hard ,, not ,,	7·7	15·0	0·51
,, ,, and ,,	8·7	14·3	0·61

TABLE 2.

Condition of Material.	Source of information.	Stress in tons per square inch. Safe stress. σ_K	Elastic limit. σ_S	Ultimate stress. σ_B
Hammered	Stühlens Ingenieur-Kalender 1888.	1·6	1·9	19
Wire		4·1	7·6	31·7
Sheet Copper, Hammered	Taschenbuch der Hütte 1875	4·2	8·9	—
,, ,, Annealed		1·6	1·9	13·3
Wire		4·2	7·6	26·7

TABLE 3.

Condition of Material.		Stress, tons per sq. in. Elastic limit. σ_S	Ultimate stress. σ_B	Alteration of Form. Total Extension per cent.	Reduction of Area per cent.	Ratio. $\frac{\sigma_S}{\sigma_B}$	See page 689 Z
Old tests.	Strips, 0·12 to 0·16 inch thick	6·0 to 9·5	13·9 to 15·4	17·3 to 24·0	—	0·43 to 0·62	
	Bars, 0·39 to 0·43 ,, ,,	6·4 to 7·8	13·0 to 13·8	17·3 to 29·0	—	0·40 to 0·57	
	Wire, 0·10 inch diam., loaded gradually in two months		16·8				
New tests.	Strips, 0·13 to 0·14 inch thick, in ordinary condition	8·0	14·5	37·2	54·7	0·555	0·68
	,, ,, ,, ,, annealed	4·0	14·3	40·9	54·7	0·28	1·46
	,, ,, ,, ,, hammered	11·2	15·2	33·5	55·3	0·745	0·45

The whole investigation is divided into two parts.

First.—The preliminary tests, dealing with the questions:—

(1) of the influence of the method of experimenting;

(2) „ „ „ „ „ condition of the material.

Second.—The main tests, from which final results are to be evolved, dealing with the questions:—

(3) of the influence of the chemical composition of the copper;

(4) of the connection and mutual reaction between the chemical composition and the mechanical treatment of the copper;

(5) of the permissible or safe working load for copper in its ordinary condition and when worked up;

(6) of the strength of riveted joints, of soldered joints, and of soldered and riveted joints;

(7) cf the influence of heating on the strength of copper.

The present Report deals with the first part only—the preliminary tests; and the following symbols are used in the Report and in this Abstract:—

E Modulus of Elasticity (Young's).

σ Stress per unit of cross-sectional area.

σ_K Safe working stress per unit of cross-sectional area.

σ_P The terms "Bearing limit," "Elastic limit," and "Limit of proportionate extension" are used somewhat indiscriminately. The point at which the extension begins to increase more than in proportion to the stress is called "Limit of proportionate extension," and the stress at this point is designated by σ_P.

σ_S The point at which the extension suddenly increases in increasing proportion to the stress—the yielding point of the material—is called the "Stretching limit," and the stress at this point is designated by σ_S. Thus σ_S appears to correspond to the Limit of Elasticity as usually understood; but in Germany σ_P is now considered as the stress at the limit of elasticity, and has superseded σ_S.

σ_B Breaking stress, or the greatest stress which occurs shortly before rupture.

σ_Z Tearing stress, or the stress which occurs at the moment of rupture; it is always smaller than σ_B in malleable materials.

f Cross-sectional area.

q Percentage of reduction of the cross-sectional area f.

t Length of one of the divisions into which the measuring length l is divided. If 20 divisions are used, $l = 20\ t$; and if 10 divisions, $l = 10\ t$. The notations employed for these two lengths are $20\ l_t$ and $10\ l_t$.

δ Percentage of extension of the whole measuring length $20\ l_t$ or $10\ l_t$ measured on 10 and 5 divisions respectively on either side of the point of fracture; and to refer the extension to the measuring length used, namely $20\ l_t$ or $10\ l_t$, the notations δ_{10} and δ_5 are used respectively.

It was considered best to use sheet copper for the preliminary experiments, because the material is more likely to be uniform in sheets than in any other form.

As copper is such an expensive material, it was considered desirable to use a new form of standard test-bar, proportionately reduced in size from the standard at present adopted, so as to admit of comparisons of results, in accordance with what Barba calls the law of similarity, or what Kick calls the law of proportionate resistances, namely:—"Geometrically similar bodies, of the same material and under the same conditions, undergo geometrically similar changes of form when subjected to equal stresses."

A new standard was accordingly adopted of the form shown in Fig. 1, Plate 152, where

a = thickness of test bar,

b = breadth,

l = length of part divided for measurement,

l_g = length of part tooled on edges,

L = length over all.

Question 1.—The influence of the method of experimenting is considered to depend upon:—

a the form of the test bar.

b the preparation of the test bar.

c the actual carrying out of the experiments.

d the difference between steadily increased and stepped loading.

a.—*Form of test-bar.*—To determine the influence of the form of the test-bar, four different proportions were proposed:—

	b	a	l	Broad. mm.	Thick. mm.	Long. mm.	Broad. ins.	Thick. inch.	Long. ins.
a Present standard	3 ×	1 ×	20	30 ×	10 ×	200 =	1·18 ×	0·39 ×	7·87
b New "	3 ×	1 ×	20	21 ×	7 ×	140 =	0·83 ×	0·276 ×	5·51
c Alternative	1 ×	1 ×	20	7 ×	7 ×	140 =	0·276 ×	0·276 ×	5·51
d "	5 ×	1 ×	20	35 ×	7 ×	140 =	1·38 ×	0·276 ×	5·51
e "	10 ×	1 ×	20	70 ×	7 ×	140 =	2·76 ×	0·276 ×	5·51

For testing round bars the form shown in Fig. 3, Plate 152, was proposed.

b.—*Preparation of test-bars.*—The copper was procured from Messrs. C. Heckmann of Duisburg-Hochfeld. The best refined copper was cast in a metal mould into a block 35·43 inches high × 37·4 inches broad × 5·5 inches thick. After being cleaned the block was gradually heated in a reverberatory furnace in $1\frac{1}{4}$ hour to a red heat, then rolled in a reversing rolling mill to about 1·18 inch thickness × 51·2 inches breadth × 118 inches length, and quenched in water whilst still at a dark heat. This removed any oxide which had formed, and left the surface nearly clean metal; and impurities which had been rolled in, as well as all surface defects, were removed. The plate was then cut into pieces 33·46 inches wide, heated again to bright redness, rolled in the opposite direction to the original down to pieces 0·47 and 0·354 inch thick, again heated to redness, and finally cooled quickly in water.

The test pieces were cut from these plates in accordance with carefully prepared plans.

Those that had to be annealed in the course of the experiments were gradually heated to redness in a furnace, and then allowed to cool gradually together with the furnace.

c.—*Actual carrying out of the experiments.*—This was done in the 50-ton machine of the establishment, fitted with a mirror and telescope for taking observations. The experiments were divided into five series, which, owing to circumstances connected with the business of the testing works, were dealt with in the order III, I, II, V, IV.

A. *Series III.—Effect of heat.*

These tests were made with hard-drawn copper wire.

a and a′, each test piece was heated, and kept for two minutes at different temperatures, ranging from 100° C. to 550° C., or 212° to 1022° F., and then plunged into water at the temperature of the room;

a″, each test piece was heated and kept at 300° C. or 572° F. for half, one, two, four, and ten minutes, and at 350° C. or 662° F. for one, four, and ten minutes, and then plunged into water at the temperature of the room;

a‴, each test piece was heated and kept at 300° C. or 572° F. for half a minute, and then plunged into water thirty-two consecutive times, and was then similarly treated at 350° C. or 662° F. two, four, and eight times consecutively;

a⁗, the test pieces were coated with different substances, to prevent or reduce the action of the metallic bath on the copper at 525° C. or 977° F.

The results are given generally in Table 5 in the Report.

1.—*Influence of once heating and then quenching* (a *and* a′).

These experiments show that the change of form is not proportional to the stress.

At 300° C. or 572° F. the increase in the rate of extension becomes noticeable;

from 325° to 350° C. or 617° to 662° F. it is still more plainly visible;

and at 400° C. or 752° F. it has become so considerable that it is not much further increased even at 550° C. or 1022° F.

Numerous curves are plotted from the results and are given in diagrams on Plate 1 of the Report. The law which governs the dependence of the increment of extension—due to the uniform increment of stress used in the experiments, namely 1·8 kilogram per square millimetre = 0·968 ton per square inch—upon the total tension in the test piece and upon the heating to the various temperatures (20° to 550° C. or 68° to 1022° F.) can be represented by a curved surface produced by the intersection of two sets of curves:—those given in Fig. 18 (Plate 1 of the Report) are for the rates of extension due to the same tensions at various temperatures, for the equidistant horizontal sections; and those given in Fig. 19 (Plate 1 of the Report) are for equal rates of extension due to varying tensions and temperatures, for the equidistant vertical sections. This ingenious idea was carried out in a plaster of Paris model, which is shown in Fig. 20, Plate 154.

The permanent extension was clearly noticeable in the hard-drawn copper wire even at a very low tension, if not indeed from zero.

It appears further that the change in the hard-drawn copper wire begins with two minutes' duration of heating at 250° C. or 482° F., and that the actual softening takes place between 300° and 400° C. or 572° and 752° F. Heating above this point up to 550° C. or 1022° F. has not a materially greater effect. From 300° to 400° C. or 572° to 752° F. the stresses of yielding and breaking fall considerably, especially the former, whilst the extension increases considerably. This is illustrated by the following figures taken from Table 7 of the Report:—

Taken from TABLE 7.

Change of Strength of hard-drawn Copper-wire by heating once to various temperatures for two minutes and then quenching in water.

Length of Test-piece measured $l = 100$ mm. $= 15\cdot9\sqrt{f}$.

(f = cross-sectional area).

Series.	Heated to Temperature		Yield-point. Tons. per square inch. σ_S	Breaking stress. Tons per square inch. σ_B	Extension per cent. δ	Ratio $\frac{\sigma_S}{\sigma_B}$
	C.°	F.°	Tons.	Tons.	Per cent.	
a	Of room		23·4	25·3		0·93
a	100°	212°	23·9	25·7		0·93
a	200°	392°	23·8	25·6		0·93
a, a″	300°	572°	22·7	24·6		0·92
a′	325°	617°	21·9	24·1		0·91
a′	350°	662°	19·7	22·2	(0·2)	0·89
a′	375°	707°	12·7	20·5	16·2	0·62
a, a′	400°	752°	3·7	16·0	40·7	0·23
a′	450°	842°	2·9	16·0	45·0	0·18
a′	500°	932°	2·7	15·6	41·0	0·17
a′	550°	1022°	2·7	15·6	(39·7)	0·17

2.—*Influence of continued heating* (a″).

3.—*Influence of repeated heating and quenching* (a‴).

Table 8 of the Report gives the general results for comparison of the four sets of experiments a, a′, a″, and a‴, from which the table on page 666 is taken.

Taken from TABLE 8.

Change of Strength of hard-drawn Copper-wire by heatings of various durations, and by heatings, each for half a minute, at various temperatures, and then quenching.

Length of Test-piece measured l = 100 mm. = $15 \cdot 9 \sqrt{f}$.
(f = cross-sectional area).

Series.	Heated to Temperature		Duration of heating.	Number of times heated.	Yield-point. Tons per square inch. σ_S	Breaking stress. Tons per square inch. σ_B	Extension per cent. δ	Ratio $\frac{\sigma_S}{\sigma_B}$
	C.°	F.°	Min.	Times.	Tons.	Tons.	Per cent.	
a, a″	300°	572°	2	1	22·7	24·6		0·92
a″	300°	572°	½	1	23·9	26·0		0·94
a″	300°	572°	1	1	23·5	25·6		0·92
a″	300°	572°	2	1	22·9	23·3		0·98
a″	300°	572°	4	1	23·2	26·0		0·89
a″	300°	572°	10	1	22·4	25·2	16·5	0·89
a‴	300°	572°	—	32	22·8	24·9		0·92
a″	350°	662°	1	1	21·3	24·9	(3·2)	0·86
a″	350°	662°	4	1	13·8	20·0	(6·8)	0·69
a″	350°	662°	10	1	4·8	17·3	(32·5)	0·28
a‴	350°	662°	—	2	21·6	25·3		0·86
a‴	350°	662°	—	4	20·8	24·1	(1·1)	0·87
a‴	350°	662°	—	8	17·0	21·3	(2·5)	0·80
a′	350°	662°	2	1	20·3	22·6	(3·9)	0·90
a	20°	68°	—	—	23·4	25·3		0·93

It thus appears that the duration of the heating, as well as the repetition of same with quenching after each heating, both have the effect of softening and weakening the hard-drawn copper wire, not much at 300° C. or 572° F., but very clearly at 350° C. or 662° F.; and it is inferred that the copper would be completely softened by extending either process sufficiently. It is a question to what extent hard-drawn copper wire may be heated without impairing its strength. Further special experiments are required to settle this point; meanwhile it seems probable that the temperature is nearly as low as 200° C. or 392° F.

4.—*Effect of coating test-pieces to prevent chemical action of the metallic bath at 525° C. or 977° F. on the test-piece* (a'''').

The experiments showed that during the relatively short time required for heating the test-pieces no evil effect need be apprehended from such action; and furthermore that the coating had hardly any effect on the results of the tests.

B. *Series I.—Elastic properties of sheet copper in different conditions of hardness.*

Three sets of three pieces each were tested: those marked D were of copper as received from the makers—i.e. rolled, heated to red-heat, and quenched in water; those marked E were annealed; and those marked F were hardened by hammering. The test bars were shaped to form b ($3 \times 1 \times 20$), $0{\cdot}83$ inch $\times$ $0{\cdot}276$ inch $\times$ $5{\cdot}51$ inches with section $= 0{\cdot}228$ square inch, and the load was applied in increments of 220 lbs. or 100 kilograms, equivalent to $0{\cdot}444$ ton per square inch, each left on for two minutes. Readings were taken immediately after the application of each increment of load, and also after intervals of one and two minutes. After every three increments of load thus applied, the whole load was removed, and the permanent set was measured. The load was then applied again, one increment at a time, one reading being taken on the addition of each, and the testing then continued in the same way. (It does not appear what

intervals of time were observed in the re-loading, but probably they were not measured, every additional load being added as soon as the readings for the previous increment were taken.)

The results are given in Tables 10 and 11, and deductions from them in a third, Table 12 of the Report.

Summary of TABLE 10.—*Results of Tests of Copper Plates: means of the series D (as received from makers) and E (re-annealed).*

Extensions given in millionths of tested length, each increment of load being 0·444 ton per square inch.

Stress. Tons per square inch. σ	Rate of Extension on first application of each increment of load. B	Rate of Extension on re-application of each increment of load. W	Difference B–W	After-stretch during first minute after first reading.	After-stretch during second minute after first reading.	Permanent Set on removal of all load after each third increment.
Tons.						
0·89	86	81	5	0	0	
1·33	99	88	11	1	1	
1·78	132	91	41	3	5	0
2·22	182	93	89	6	9	
2·67	331	100	231	22	30	
3·11	734	111	623	42	63	49
3·56	1675	104	1571	82	150	
4·00	3903	116	3787	150	251	
4·45	5018			283	451	789
4·89	5583			337	494	

Table 10 of the Report contains the results for soft plates D and E; there is practically no difference between these two sets of results, and they are summarised in the preceding table, page 668.

The following conclusions are drawn from these results:—

The rate of extension is considerably greater on the first application of the load than on its re-application.

The rate of extension increases from the first application of load, or there is no proportionate extension to the stress; not even by immediate and repeated re-application of the load within the limits of the previous stresses.

The metal evidently becomes stiffer.

Table 11, pages 670–1, contains the results of tests of plates F hardened by hammering. The conclusions drawn from these results are similar to those from the results with soft copper, only in a considerably reduced degree.

It is suggested that the laws which Bauschinger found applicable mainly to steel and iron may be found applicable also to copper; they are thus stated:—

1. When a body is subjected to tensile forces which, beginning from zero, produce stresses that exceed the limit of proportionate extension of the material, this limit will be raised, provided the material is not already in an artificially affected condition. If in the repetition of the test the stress is allowed gradually to exceed that stress which caused the first raising of the limit, a further increase of this limit will take place, till finally the yield-point of the material will be reached, or even slightly exceeded.
2. In this case the limit of proportionate extension falls considerably, and may be reduced to nearly zero if the yield-point is greatly exceeded.
3. If the test-piece is then allowed to rest, the limit of proportionate extension will gradually rise again, first quickly and afterwards slower; in the course of years it may rise beyond the original yield-point, and in some circumstances even exceed the previous stress.

Summary of TABLE 11.

Results of Tests of Copper Plates: means of the series F, *hardened by hammering.*

Extensions given in millionths of tested length, each increment of load being 0·444 ton per square inch.

Stress. Tons per square inch. σ	Rate of Extension on first application of each increment of load. B	Rate of Extension on re-application of each increment of load. W	Difference B–W	After-stretch during first minute after first reading.	After-stretch during second minute after first reading.	Permanent Set on removal of all load after each third increment.
Tons.						
0·89	81	80	1	0	0	
1·33	81	82	–1	0·5	0·5	
1·78	85	84	1	0·5	0·5	0
2·22	81	83	–2	1·0	2·5	
2·67	82	86	–4	1·0	1·0	
3·11	85	84	1	0·5	0·5	3
3·56	83	86	–3	1·5	1·5	
4·00	82	84	–2	1·5	2·0	
4·45	92	86	6	1·0	1·0	4
4·89	87	85	2	2·0	2·0	
5·33	88	85	3	1·0	3·5	
5·78	92	86	6	3·0	3·5	5
6·22	92	84	8	0·5	1·5	
6·67	94	87	7	2·0	4·5	
7·11	91	85	6	2·5	5·0	11

Summary of TABLE 11 (*continued*).

Results of Tests of Copper Plates:
means of the series F, *hardened by hammering.*

Extensions given in millionths of tested length,
each increment of load being 0·441 ton per square inch.

Stress. Tons per square inch. σ	Rate of Extension on first application of each increment of load. B	Rate of Extension on re-application of each increment of load. W	Difference B-W	After-stretch during first minute after first reading.	After-stretch during second minute after first reading.	Permanent Set on removal of all load after each third increment.
Tons.						
7·56	94	88	6	3·5	5·0	
8·00	108	86	22	2·0	5·0	
8·44	108	86	22	4·0	5·5	18
8·89	102	88	14	5·0	8·0	
9·33	118	88	30	9·0	12·0	
9·78	139	94	45	10·5	15·5	47
10·22	127	88	39	8·5	17·5	
10·67	177	95	82	13·0	22·0	
11·11	195	94	101	21·0	27·5	164
11·55	212	(94)		29·5	41·5	
12·00	407	(103)		60·5	82·0	
12·45	1176			119·0	194·0	380
12·89	3737			463·5	797·5	
13·34	6655			7220·0	9930·0	

4. Stresses above the original yield-point have the effect of raising this limit at once. During the rest after removal of the load, the yield-point rises in course of time to above the stress previously applied. This rise is very noticeable already after a single day, and continues for weeks, months, and years.
5. Stresses above the original yield-point generally have the effect of lowering the modulus of elasticity $E = \frac{\sigma}{\epsilon}$, where σ = stress per unit of sectional area, and ϵ = extension per unit of length due to σ. During the rest after the removal of the load, the modulus of elasticity rises; but slower than the limit of proportionate extension. After several years the modulus is found to have risen considerably above its original value.

It thus appears that soft copper behaves in opposition to the fifth law, and hard copper too, though much less markedly.

The following conclusions are drawn from the experiments:—

Hard sheet copper only becomes appreciably stiffer by the repeated application of the load when the stress reaches $3\frac{1}{4}$ tons per square inch.

The after-stretch during the first and second minutes after the first reading is noticeable from the beginning in the soft copper, but only when the stress reaches $4\frac{1}{2}$ to $6\frac{1}{2}$ tons per square inch in hard copper.

The permanent set begins with very small tensions, both in soft and in hard copper, but is naturally much greater in the soft than in the hard.

In the Report Table 12 gives the principal results of the experiments recorded in Tables 10 and 11, besides sundry quantities deduced from them, of which the principal are $\frac{\sigma_S}{\sigma_B}$ and $Z = \frac{\delta_{10}}{100} \times \frac{\sigma_B}{\sigma_S}$; Z will be dealt with later on (see page 689).

C. *Series II.—Speed of carrying out Tests.*

Several experiments were made, and the results tabulated in Tables 13 and 14; but as they proved that the speed in the application of the load does not affect the result to any appreciable extent, it will suffice here simply to state the conclusions arrived at.

The speed of flow, taken even over the range from 0·2 to 22·0 per cent. extension per minute, has no appreciable influence on the highest or ultimate tensile stress, and a variation of the speed of extension between 0·5 and 40·0 per cent. per minute certainly does not affect the maximum load by much more than 2 per cent.

The speed of flow has only a very small influence on the ultimate extension, and on the reduction of area; and both are reduced with an increased flow;

It has a noticeable—but, compared with the other influences affecting the result, a practically unimportant—effect on the yield-point, which is raised by an increased flow.

This result is of great practical value, as it shows that the speed of testing may be considerably increased. But from a scientific point of view the question requires further study.

D. *Shape of Tensile Test-pieces.*

This is very fully gone into and treated under several heads.

a.—*Influence of the method of measuring the extension on the numerical value of same.*—The total extension was found to be greatest when fracture occurred in the middle of the length of the bar, or $\frac{1}{2}\,l$ from the end. Taking this as 100, the result of a series of tests on ingot-iron of different forms is given in the summary (page 674) of Table 15 in the Report.

The method of measuring is next dealt with. The Berlin Conference decided that for flat bars the mean should be taken of the extensions along the two edges and on one flat side, and this method has been adopted. Calling the thickness a and the breadth b, the effect of this method of measurement of the extension is shown in Table 17 of the Report, from which the second table on page 674 is condensed.

Summary of TABLE 15.

Effect of Position of Fracture with regard to ends of test-piece.

Position of Fracture from end	$\frac{1}{2}\, l$	$\frac{1}{3}\, l$	$\frac{1}{4}\, l$	at end
Extension with Round Bars	100	97·7	96·1	89·7
„ „ Flat „	100	97·5	96·2	86·9

Condensed from TABLE 17.

Difference of Extension on edges and on flat side of test-bar.

	mean of edges a	one flat side b	mean $\frac{a+b}{2}$	by automatic recorder
	per cent.	per cent.	per cent.	per cent.
Extension of Soft Copper . . .	48·2	47·9	48·05	44·8
Extension of Hard drawn Copper .	29·1	28·6	28·85	26·2

Thus the extension is greater on the edges than on the flat side. The difference is smallest with bars of square section, and greatest with bars of form e, where $b = 10\ a$.

b.—*Influence of the form of the heads or ends of the test bars.*—Although in long bars those portions at a little distance from the point of fracture may be considered to stretch uniformly along the length of the bar, whilst in those in the immediate vicinity of the fracture the extension rapidly increases as the point of fracture is approached, yet, in such short bars as all test-pieces are, there is no portion of the length of the bar in which the extension is uniform: the rate of extension varies in the whole length of that part of the bar which is measured. To exclude at least the greatest part of the influence of the heads on the results, it is considered right to use for results those test-bars only which break within the middle third of the measured length, and to throw out all the rest.

c.—*Influence of the length measured.*—Numbers of experiments were made with the extensions measured on lengths respectively of five, ten, and twenty units, say $l = 5t$ and $10t$ and $20t$ respectively, the test-bars being of ingot iron. The results are given in Table 19 of the Report, and are summarised as follows :—

Summary of TABLE 19.

Influence of the measured length on the numerical value of the extension.

Test-pieces of ingot iron;

extensions in percentage of test-length l, which is taken with fracture in middle.

l_t 20, l_t 10, and l_t 5 correspond with $n = \frac{l}{\sqrt{f}} = 11 \cdot 3$, $8 \cdot 5$, and $3 \cdot 5$ respectively, where $f =$ area of cross section.

Measuring length	l_t 20	l_t 10	l_t 5
Extension per cent.	31·8	40·8	55·3
Ratio of extensions	100·0	128·3	173·9

This shows clearly the well-known effect of the local contraction at the point of rupture on the extension : an effect which is greater with soft materials like copper than with iron.

d.—*Influence of the form and magnitude of the cross section.*—Bauschinger has investigated this point as well as the previous one at great length, experimenting with ingot iron. He has laid down the following rule :—

> Within the limits of testing, as carried out in ordinary practice, the form of section does not affect the results, and especially not the extension, provided the length is proportional to the square root of the sectional area f, that is, provided $l = n \sqrt{f}$.

This is shown in the Report by Table 20, which is here condensed as follows :—

Summary of TABLE 20.
Influence of shape of cross-section on extension: all test-pieces having $l \div \sqrt{f} = 8 \cdot 5$.

Test-Bars.	Round	Flat							
Ratio $\frac{\text{breadth}}{\text{thickness}} = \frac{b}{a}$	1	1·3	1·4	1·5	1·7	1·8	2·1	2·5	3·0
Extension per cent.	32·9	33·2	31·0	33·3	32·7	33·0	32·3	(29·9)	33·25
No. of bars tested	7	2	1	1	9	1	3	1	2

But this is again affected by the proportions of the ends or heads of the test-bars, as shown by Barba, whose investigations showed that:—

> The extension obtained in a short measuring length from long bars cannot be compared with that obtained from short bars with the same measuring length, even if $n = \frac{l}{\sqrt{f}}$ is the same in both cases.

For instance, with $\frac{l}{\sqrt{f}} = 11 \cdot 3$ Barba got an extension $\delta = 34 \cdot 5$ per cent. with long bars, and $\delta = 28 \cdot 3$ per cent. with short bars, or a ratio of 100 to 82.

Therefore if test-bars of other measurements are to give the same results as the standard bar of 20 millimetres or 0·787 inch diameter and 200 millimetres or 7·87 inches measuring length, it is indispensable to determine what allowance should be made to exclude the influence of the heads. Until this can be done, the decision arrived at by the Vienna Conference in 1893 must be accepted as a great step in advance, namely:—

> In order to make proportional extension independent of the form and magnitude of the sectional area, the measuring length l must be proportional to the square root of the sectional area f; and, based upon the test-bar which has already become an international standard (20 millimetres diameter × 200 millimetres working length), the measuring or test-length should be made so that $l = 11 \cdot 3 \sqrt{f}$.

e.—*The Law of Similarity.*—This is dealt with further at this point, but requires no more notice here.

In order to obtain comparable results in accordance with this law, it is proposed to adopt the following proportions of test-bars, as in Fig. 43, Plate 153, for round bars, for which $f = \frac{d^2\pi}{4}$; whence $d = 1 \cdot 128 \sqrt{f}$, say $1 \cdot 13 \sqrt{f}$. Then

a for round turned bars with ends shaped as in Fig. 43.

$d = 1 \cdot 13 \sqrt{f}$; $d_1 = 1 \cdot 5 \sqrt{f}$; $d_2 = 2 \sqrt{f}$;

$l_g = 12 \cdot 5 \sqrt{f}$; $L = 20 \sqrt{f}$;

$l = 11 \cdot 3 \sqrt{f}$; and $l_t = 0 \cdot 565 \sqrt{f}$.

b for plain parallel round bars, not turned

$L = l_g = 18\ d$ or $= 20 \sqrt{f}$;

$l = 11 \cdot 3 \sqrt{f}$; and $l_t = 0 \cdot 565 \sqrt{f}$.

c for square or rectangular bars, not tooled, and breadth not exceeding four thicknesses

$L = l_g = 20 \sqrt{f}$;

$l = 11 \cdot 3 \sqrt{f}$; and $l_t = 0 \cdot 565 \sqrt{f}$.

d for shaped square or flat bars of uniform thickness throughout, and breadth not exceeding four thicknesses, as in Fig. 44, Plate 153,

$l_g = 12 \cdot 5 \sqrt{f}$; $b_1 = 1 \cdot 5\ b$; $f = ab$;

$c = b =$ distance of grip from l_g at either end;

$L = 12 \cdot 5 \sqrt{f} + 2\ b = 12 \cdot 5 \sqrt{f} + 2\ c$;

$l = 11 \cdot 3 \sqrt{f}$; and $l_t = 0 \cdot 565 \sqrt{f}$.

f. *Influence of the form of the test-bar on σ_P, σ_S, σ_B, and q.*—An examination of the results of Bauschinger's tests shows that the cross section and the form of the test-bar have very little influence on the modulus of elasticity E, elastic limit σ_P, yield-point σ_S, and ultimate stress σ_B, or on the reduction of area q, or on the extension δ, provided δ is determined from measuring lengths which are proportional to $\sqrt{f}$ and lie within the limits of $8 \sqrt{f}$ and $17 \sqrt{f}$.

Arranging the results with reference to varying values of $\frac{l}{\sqrt{f}}$ also shows that the form and magnitude of the cross section, as well as the ratio $l_g : f$, had practically no influence on the stresses E, σ_P, σ_S, and σ_B; but, on the other hand, the extension δ and the reduction of area q were affected a little, appearing to increase slightly with $\frac{l_g}{\sqrt{f}}$.

Some experiments of Barba's with ingot-iron, on the influence of the form of the test-bar, are then given in Table 21 of the Report; but the influence of the cross section and form of test-bar is not easily separated from that of the heads, and an investigation of this latter is being carried out at the experimental works in Berlin; it need not be further touched upon here.

E. *Series V.—Comparison of Test-bars.*

Comparison is made of the old standard test-bar a (page 662), of cross section 30 × 10, with the new form b, of cross section 21 × 7, proposed for the experiments on copper, in order to show whether, and if so to what extent, the "Law of Similarity" is applicable to soft and to hard-drawn copper; and also comparison of the forms a and b, with the other forms c, d, and e already mentioned (page 662). Numerous experiments were made, some with bars in the condition as received from the makers, some with bars annealed, and others with hammered bars; they were conducted in the same way as before. The results are given in Table 22 in the Report, and in numerous diagrams plotted from these results; and they are considered under several heads, as follows:—

a. *Results from measurements with mirror and telescope.*

1.—*Increments of extension.*—These were found to increase from the beginning in soft copper, and nearly so in hard copper, as already stated.

As regards the general comparison of the various forms of test-bars, it was found

that with soft copper the variations of form tried had no appreciable regular influence on the rate of extension;

and that with hard copper the material differed so much in the different test-bars that the influence of the form on the results could not be observed.

2.—*Extension during the first and second minutes after each increment of load was applied.*—For soft copper this additional extension is noticeable even with a stress of 1·27 ton per square inch. During the second minute it is less than during the first, up to stresses over 4·45 tons per square inch; whence it may be inferred that with stresses below this amount the extension would gradually cease and the material come to rest.

The form of the test-bar does not appear to have any appreciable influence on this after-stretch.

With hammered bars the additional extension appeared to be first noticeable with stresses between 4·45 and 6·35 tons per square inch; but the difference in the material of the several bars rendered impossible any conclusion as to the influence of the form.

3.—Extension diagrams are given in the Report to illustrate the complete results of the experiments. In soft copper they appear to vary for the different forms of test-bar; they even differ considerably for forms a and b, thus contradicting the "Law of Similarity." No explanation can be offered for this. Hard copper gave similar results with both forms.

b.—*Extension in the Subdivisions of the Bars.*—Experiments were made to determine the extension in the separate subdivisions of the measuring or test-length of the bars; but the results were not sufficiently consistent to enable any law to be determined. The investigation must be resumed at some future time.

c.—*Principal numerical results.*—The results in Table 22 generally corroborate those previously arrived at, and the principal ones are condensed into Table 24. The following conclusions are deduced:

Within the limits of form of test-bars used in series V (b, c, d, and e) the magnitude of the sectional area and the form of the bar have so very little influence on the ratio $\frac{\sigma_S}{\sigma_B}$ that they may be neglected for practical testing.

On the other hand the extension and the reduction of area are affected considerably; the extension increases whilst the reduction of area decreases as the ratio $\frac{l}{\sqrt{f}}$ diminishes. And correspondingly the value of Z is affected by the form of the test-bar in the same way as the extension.

An examination of the results in Table 22 does not corroborate the correctness of the "Law of Similarity" as much as other experiments seemed to warrant. The practical conclusions to be drawn from the results of series V for future experiments with copper are:—

It is expedient to use one form of test-bar only, namely form b as far as possible; and in all cases where this is not possible, to use a proportional form differing from it as little as possible. If a proportional form is not possible, then at any rate the ratio $n = \frac{l}{\sqrt{f}}$ should be constant, with $n = 11 \cdot 3$.

The subdivisions of the measuring or test length should always be equal to $0 \cdot 565 \sqrt{f}$; and the extension should be determined for 5 or 10 divisions on either side of the fracture; and 10 divisions on either side of the fracture should be taken for the basis of comparison.

F. *Series IV.—Influence of the method of preparing the test-bars.*

Strips of copper $1 \cdot 85$ inch $\times$ $0 \cdot 35$ inch $\times$ $11 \cdot 3$ inch were hammered cold down to $0 \cdot 295$, $0 \cdot 256$, and $0 \cdot 216$ inch thicknesses in the middle part between the heads; and then shaped out in the hammered part to the width of form b, namely to $0 \cdot 83$ inch. Tests were made with bars

as delivered from makers;

hammered to varying thicknesses and then shaped;

hammered, then annealed, and then shaped;

annealed and then shaped;

shaped and then annealed;

shaped, then heated, and then quenched;

with the following results, as shown in Table 25 in the Report:—

Cold hammering alone raised the yield-point to about four times its original value, whilst it did not much increase the ultimate strength; it reduced the extension considerably, and lowered the reduction of area slightly.

By subsequent annealing, hammered copper is nearly restored to its original condition, if that was quite soft.

Bars which were shaped first and then annealed were decidedly softer than those annealed first and then shaped.

The quenched bars were a little harder than those which had been annealed; this appears mainly in the yield-point and the extension.

Tests were next made with bars of soft copper which were heated to, and kept for three minutes at, various temperatures ranging from 300° to 550° C. or 572° to 1022° F., and then quenched. The results are given in Table 26 in the Report. The effect of heating was hardly worth mentioning; at most the yield-point fell a little as the heating increased. Thus, if sheet copper has been heated and annealed, it will not be much affected by any subsequent heating that does not exceed the temperature to which it had been heated previously.

Tests were then made with three bars shaped with square corners at *a a*, Fig. 11, Plate 152. These did not break at *a a*, but at 1·18, 1·57, and 0·39 inch away from that section.

Next tests were made with soft copper bars having a hole perforated through the middle of each, with the following results:—

Punching a hole 10 mm. = 0·39 inch diameter when cold raises the yield-point and lowers the ultimate strength considerably.

If the hole is then rimered out to 11 and 12 mm. (0·43 and 0·47 inch) diameter, the yield-point is still further raised, but the deleterious effect of the punching on the ultimate strength is only slightly lessened.

With a bored hole 10·5 mm. = 0·41 inch diameter the yield-point and ultimate stress were both raised above those of the solid unperforated bar.

These results are given in Table 27 in the Report.

G. *Re-testing bars which had already been torn asunder in testing.*

A series of experiments was made with small test-bars proportionately shaped out of halves of test-bars torn asunder in previous tests. The results are given in Table 22 already mentioned.

The pieces selected had been allowed to rest for a little over three years: one set was re-tested as it was; and a second set was heated to, and kept for six minutes at, 500° C. or 932° F. in a lead bath, and not quenched. Each set contained three bars of copper tested as it had been received from the makers, three bars of copper which had been annealed, and three bars of copper which had been hammered before heating. The result was:—

The unannealed test-bars of soft copper had 3·7 times the previous yield-point stress and nearly 30 per cent. greater ultimate strength; whilst the extension was reduced to one-fifth of the previous amount, and the reduction of area to about three-quarters of what it had been.

The actual results of the tests of the bars from the hammered copper were practically the same as those from the soft copper; the changes were similar in both cases, only considerably greater with the soft than with the hard copper.

After heating, the hammered and soft copper bars gave practically identical results.

All the above results are detailed in Tables 28, 29, and 30 in the Report; and it is pointed out that it is desirable these instructive experiments should be continued on a more extended scale and with different materials. Meanwhile these experiments show that the quality of a material can be ascertained only by testing it in a definite normal condition, so as to eliminate the variable influence of mechanical treatment.

H. *Strength of copper in a heated state, and influence of admixture of foreign substances.*

Some experiments were made with copper sent to be tested from the Royal Dockyard at Wilhelmshaven, its make and previous

treatment being unknown. The test-bars were all turned to 10 mm. (0·394 inch) diameter for a length of 100 mm. (3·94 inches), and the measuring length was 90 mm. (3·54 inches). The test-bars were heated up to 300° C. or 572° F., in vapours of different substances, and to 400° C. or 752° F. in a metal bath. The results are given in Table 31 in the Report, from which the following table is condensed.

Condensed from TABLE 31.—*Strength of Heated Copper.*

Temperature.		Yield-Point. Tons per square inch. σ_S	Ultimate Stress. Tons per square inch. σ_B	Modulus of Elasticity. Lbs. per square inch. E	Total Extension. δ	Reduction of area. q	Ratio $\frac{\sigma_S}{\sigma_B}$	Z
C.°	F.°	Tons	Tons	Lbs.	Per cent.	Per cent.		
Of	room.	17·1	18·5	(17,070,000)	14·9	54·6	0·92	0·16
100°	212°	16·2	17·5	19,100,000	8·2	56·4	0·92	0·88
200°	392°	13·8	15·4	15,700,000	7·8	52·4	0·89	0·88
300°	572°	9·5	13·2		10·7	43·3	0·69	1·5
400°	752°	5·1	9·1		6·7	9·8	0·56	1·32

These results are not very conclusive, and it is pointed out that the copper may not have been of uniform quality or composition, as there was considerable discrepancy in the behaviour of different bars at the same temperature, and that further investigation is required.

Table 32 gives results of tests collected by Mr. Rudeloff from English sources. These experiments were made with brazed sheet copper and brazed copper pipes at temperatures varying from 12·8° to 210° C., or 55° to 410° F. Some were also made with sheet copper which had been overheated.

The results are not very consistent, but they show that as the temperature increases :—

the ultimate strength is always reduced ;
,, extension is generally reduced ;
,, reduction of area is generally increased ;
,, elastic yield-point appears to be generally reduced.

A summary of the results of Professor Roberts-Austen's experiments made for the Research Committee of the Institution of Mechanical Engineers * follows in Table 32a in the Report. However much ability was displayed in these English experiments, they were not sufficiently numerous, nor conducted on a sufficiently broad basis. They indicate the regular influence of arsenic, but do not determine its magnitude. R. H. Thurston, in his "Materials of Engineering," 1884, page 271, quotes results of tests upon copper containing phosphorus by Anderson, given in Table 33 in the Report, which show that the ultimate strength was considerably increased by the admixture of phosphorus up to 0·04 per cent. The original strength of rolled copper being 15·2 tons per square inch, it increased as phosphorus was added till it reached 22·5 tons per square inch, when it contained 0·04 per cent. of phosphorus.

In the Report here follows Table 34, a collection from a number of authorities, of the principal properties of copper, such as working stress, breaking stress, modulus of elasticity, extension, and contraction of area.

I. *Impact Experiments.*

These experiments were made with small cubes of 10 mm. and 7 mm. (0·394 and 0·275 inch) sides, and a drop-weight G = 56·55 kilograms, or 124·67 lbs. The fall of F metres was so adjusted that the work done (a) per cubic centimetre of the volume J of the cube $= \frac{G \times F}{J}$ was 15 and 20 and 30 kilogram-metres (or 1,777·5 and 2,370 and 3,555 foot-pounds per cubic inch) for three sets of tests respectively in each series. The series consisted of :—

A. Sheet copper as received.

B. Sheet copper hammered down from 12 mm. (0·474 inch) thickness to 10 mm. (0·394 inch).

C. Sheet copper hammered down from 12 mm. (0·474 inch) thickness to 7 mm. (0·275 inch).

D. Sheet copper—

a. as received.

* Proceedings 1893, pages 607 and 627.

b. reduced from 12 mm. (0·474 inch) thick to 10·5 mm. (0·413 inch) by steady pressure.

c. reduced from 12 mm. (0·474 inch) thick to 10·5 mm. (0·413 inch) by blows.

E. Sheet copper—

a. as received.

b. reduced from 12 mm. (0·474 inch) thick to 7·5 mm. (0·285 inch) by steady pressure.

c. reduced from 12 mm. (0·474 inch) thick to 7·5 mm. (0·285 inch) by blows.

The cubes of series *A*, *B*, and *C*—

a. were heated to a temperature t° before each blow, and then tested warm as quickly as possible.

b. some of the cubes from *B* and *C* (marked B_b and C_b), which had been heated in the metal bath, were quenched in water at 20° C. or 68° F., and then tested cold.

The results of these experiments are given in Table 35 in the Report, which shows the percentage of the original height to which the cubes were reduced by pressure or repeated blows at different temperatures; thus for each temperature—

4 blows of $\frac{G.F}{J}$ = 15 gave total $\frac{G.F}{J}$ = 60.
3 „ „ = 20 „ „ „ = 60.
2 „ „ = 30 „ „ „ = 60.

The results for the total work produced $\frac{G.F}{J}$ = 60 are collected in the table on page 686, taken from Table 35, and afford a good means of comparing results.

The results show:—

The harder hammering involved in reducing the strips to 7·5 millimetres (0·295 inch) thickness, instead of only to 10 millimetres (0·394 inch), had no appreciable effect.

The cubes of hammered copper required considerably more work expended upon them than did those of soft copper to reduce them to the same extent, both tested warm.

Extract from TABLE 35.

Results of Impact Tests with Copper Cubes.

Series		A	B		C		D			E		
Temperature.	Number of Blows.		a	b	a	b	a	b	c	a	b	c
20° C. 68° F.	4	31·4	33·6	33·6	32·9	32·9	32·0	33·9	34·9	31·4	35·5	
	3	30·4	32·7	32·7	32·9	32·9	30·5	33·0	33·6	31·4	35·5	34·7
	2	29·4	31·7	31·7	32·9	32·9	30·0	31·7	32·7	30·0	34·2	32·9
100° C. 212° F.	4	20·6	29·7	33·6	29·2	34·2						
	3	27·4	28·7	32·7	29·2	32·9						
	2	28·7	28·7	32·0	29·2	34·8						
200° C. 392° F.	4	24·5	24·7	32·0	27·8	32·9						
	3	22·5	25·7	32·7	27·8?	31·5						
	2	24·5	25·7	31·4	26·4	30·6						
300° C. 572° F.	4	20·6	20·8	32·6	18·1	34·2						
	3	18·8	20·8	30·6		31·5						
	2	19·6	19·8	31·7	19·5	31·5						
350° C. 662° F.	4		21·8	34·0		32·9						
	3	17·8	15·9	33·0		31·5						
	2	17·6	19·8	32·3	20·8	30·1						
400° C. 752° F.	4	15·7	18·8	33·0	18·3	31·5						
	3	16·6	16·8	32·0	16·7	32·0						
	2	15·7	18·8	32·0	18·1	31·9						
450° C. 842° F.	4			33·0		32·0						
	3	15·7	14·9	32 0	(17·8)	30·6						
	2	15·8	15·8	32·0	15 3	30·6						
500° C. 932° F.	4			31·0		32·4						
	3		14·9	32·0	15·3	28·2						
	2	14·9	14·9	31·0	15·3	31·0						

It does not appear to make any difference whether the initial compression is effected by pressure or by blows.

The resistance to compression decreases considerably with both hard and soft copper when tested hot.

Cubes in series B_b and C_b, which had been quenched and were tested cold, were not affected by reheating till the temperature exceeded 300° C. or 572° F.

For these experiments also the author has supplied numerous curve diagrams, plotted from the results given in the tables, which serve to elucidate the results and the arguments based on them. As in the case of the extensions due to different stresses at varying temperatures, he has again resorted to the ingenious expedient of representing the results of the experiments by the curved surfaces of solids, which were made of plaster of Paris, to the curves plotted from the results in the tables of the impact experiments. These solids are represented in Figs. 73 and 74, Plate 154.

K. *Bending Tests.*

It had been intended to carry out a carefully arranged series of bending tests, but through a misunderstanding this was not done; all the test-bars were simply doubled up and closed, a test which they all stood perfectly.

Not to skip this part of the subject altogether at this stage of the investigation, a few test-pieces were cut from the remains of these bars, and subjected to bending tests, thus: Nos. 1 and 2 were bent in a screw press; and Nos. 3 to 12 in a vice fitted with copper clamps, whose edges were rounded to a radius of 4 mm. or 0·157 inch, the free projecting piece of the test-bar being about 100 mm. (3·94 inches) long.

A bend to the right or left through 90° and back is called one complete bend; the bar is first bent to the right through 90° and back, next to the left through 90° and back, and so on. The results are given in Table 36, of which the following is a summary.

These results are much too meagre and unsatisfactory, and a better set of experiments must be arranged for the principal tests. The screwed bars do not appear to be suitable for these tests, for,

although those used were of good and tough copper, they broke at the bottom of the thread on the return bend.

Summary of TABLE 36.—*Bending Tests.*

No. of tests.	Cross-sections breadth × thickness.	No. of bends, mean.	Remarks.
1 and 2	0·94 in. × 0·47 in.	$2\frac{3}{8}$	The edges of all these test-bars were rounded to about 1 mm. or 0·04 inch radius.
3, 4, 5, and 6	0·55 in. × 0·276 in.	5	
7 and 8	0·47 inch diameter	$1\frac{1}{4}$	End of thread not turned off, bottom of thread round.
9, 10, 11, & 12	0·256 inch diameter	1 bare	End of thread turned off, bottom of thread round.

L. *The significance of the expressions* $\frac{\sigma_S}{\sigma_B}$ *and* $Z = \frac{\sigma_B}{\sigma_S} \times \frac{\delta_{11\cdot 3}}{100}$.

The use of the elastic and ultimate limits of stress and the extension of copper, for determining the condition of the material or the mechanical manipulation it has undergone, is dealt with in this section.

Let σ_S stand for the stress per unit area at the yield-point; σ_B for the ultimate stress per unit of original area, or rather the maximum stress before fracture, which is usually greater than the stress at the actual moment of rupture; and δ for the percentage of extension taken on the whole measuring test-length. σ_S increases with the hardness of the material much more than σ_B, so that the ratio $\frac{\sigma_S}{\sigma_B}$ increases with the hardness of the material; for soft copper it is between 0·2 and 0·3, and rises to over 0·9 for hard hammered copper.

Plotting the curve representing the stresses and corresponding extensions, the author points out that the ratio of the area enclosed by the curve to the circumscribed rectangle increases with the hardness of the copper, and he calls this ratio ξ, and considers it a very reliable indication of the condition of the material. But

the graphical process of getting at ξ is too tedious to allow of this ratio coming into practical use for comparisons. In many of the tables in the Report the ratio $Z = \frac{\sigma_B}{\sigma_S} \times \frac{\delta}{100}$ is used, which can be derived directly and easily from the values of σ_B, σ_S, and δ obtained from the experiments; and the author believes that this ratio gives a correct indication of the mechanical condition of the material, and that it should come into general use in future. It was found that for—

Soft copper	$Z = 1 \cdot 2$ to $3 \cdot 6$
Hard hammered copper . .	$Z = 0 \cdot 05$ to $0 \cdot 5$
" drawn " . .	$Z = 0 \cdot 03$ to $0 \cdot 25$.

As already explained, the value of n in the formula $l = n\sqrt{f}$ should be $11 \cdot 3$; and to indicate that this value is used, it is proposed to use it as a suffix to Z and δ, writing $Z_{11 \cdot 3}$ and $\delta_{11 \cdot 3}$; so that finally, as a result of these preliminary experiments, the ratio proposed for practical use to indicate the mechanical condition of the material under test is

$$Z_{11 \cdot 3} = \frac{\sigma_B}{\sigma_S} \times \frac{\delta_{11 \cdot 3}}{100}$$

M. *Safe Working Stress of Copper.*

These experiments have shown that, with hard-drawn or hammered copper, heating to not more in all probability than 250° C. or 482° F., if long continued or often repeated, will affect the strength. The yield-point, which is most raised by hammering, and which is also most, as well as first, reduced by heating, is really more important than the ultimate stress in the determination of the safe working limit of stress. But these preliminary trials are not sufficient to fix this safe limit. For this purpose the main experiments must be undertaken, dealing with the effect of long-continued application of stress, subsequent period of rest, then shock, heating, &c.

A knowledge of the effect of the admixture of foreign ingredients on the properties of copper is also most important.

Meanwhile the safe working stresses, in accordance with the most recent data, are given in Table 34 in the Report, which may be summarised thus :—

Summary of TABLE 34.—*Safe Working Stresses for Copper.*

Material.	Authority.	Steady load. Tons per sq. inch.	Live load. Tons per sq. inch.	Blow. Tons per sq. inch.
Sheet copper . .	Bach . .	3·8	2·5	
Cast ,, . .	Thurston .	2·3	1·4	1·1
Rod ,, . .	,, .	3·2	2·0	1·6
Copper wire . .	,, .	5·33	3·4	2·7
Hammered copper .	Reuleaux .	1·6		
Copper wire . .	,, .	7·6		

N. *Conclusions.*

Referring to the arrangement of the whole investigation—preliminary and main experiments—under the seven heads given in the early part of this Abstract, page 660, the answers so far obtained to the seven questions may be thus summarised:—

Question 1, a to d.

a. The form of the test-bar has an important influence on the result, especially as regards extension. To reduce this influence to a minimum, the bars should be proportionately shaped, according to section **D**.

b. The manner of preparing the test-bars may have an influence on the results. Cutting tools only should be used in their preparation, and hammering should be avoided; and the proposals made by the conferences for deciding upon uniform methods of testing should be acted on as far as possible.

c. The influence of speed in making the test is so small that it may be neglected.

d. The influence of applying the load by regular increments, as compared with a steady and gradual increase of the load, is practically inappreciable, and may be neglected.

Question 2, a to c.

a. It is possible to produce a normal condition of test-bar by heating; see section **F**.

b. The test-bar should be heated to at least 500° C. or 932° F., and then quenched in water.

c. Heating repeatedly to 500° C. or 932° F. for several minutes and then annealing has very little effect. At temperatures between 250° and 500° C. or 482° and 932° F. repeated heating has a similar effect to prolonged heating at the same temperature.

Questions 3 to 7, page 660, concerning the main experiments, have mostly been only just touched on and partly dealt with. They will have to be answered by the main experiments yet to be undertaken. These main experiments will have to be very extensive, necessitating important additions to the apparatus in the experimental works, as it is intended to investigate all the various qualities of copper in the market, and to make numerous experiments with the alloys of copper, as well as to determine the laws which govern the mechanical properties of copper.

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Parts 3-4.

EDINBURGH ELECTRIC LIGHTING.

Plate 140.

EDINBURGH ELECTRIC LIGHTING.

Fig. 2. *Sectional Plan of Boiler House.*

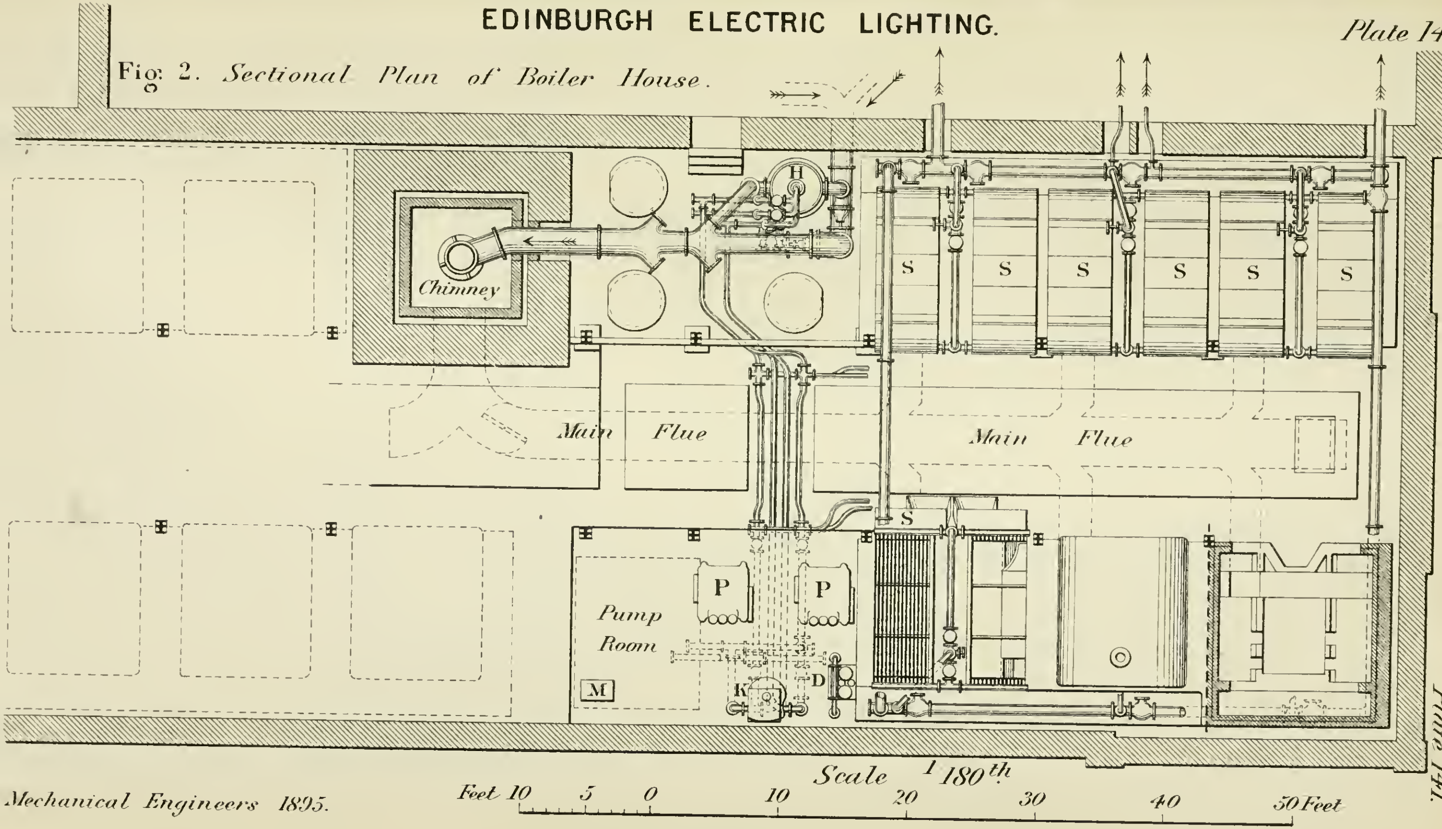


Plate 141.

EDINBURGH ELECTRIC LIGHTING.

Fig: 3. *Longitudinal Section of Boiler House.*

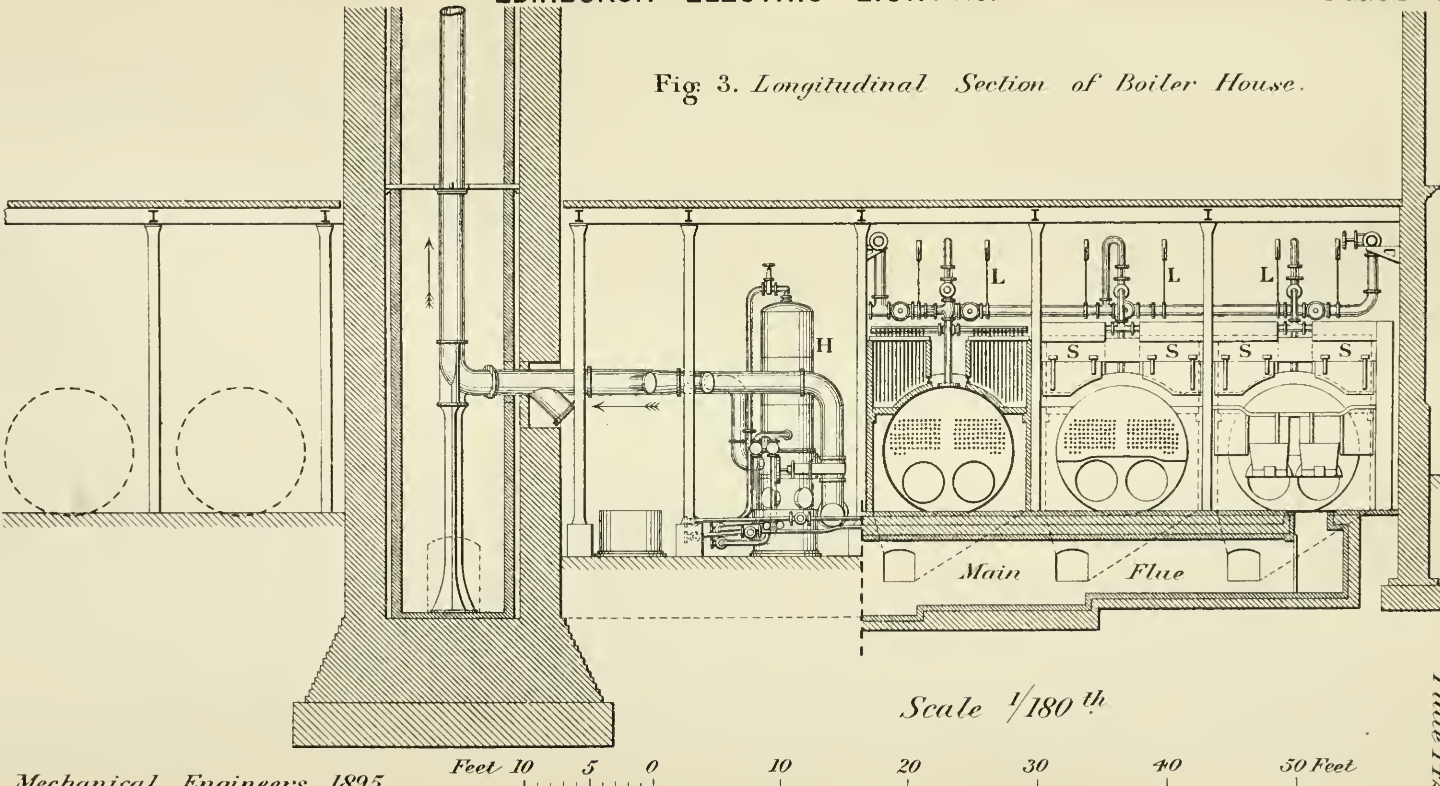


Plate 142.

EDINBURGH ELECTRIC LIGHTING.

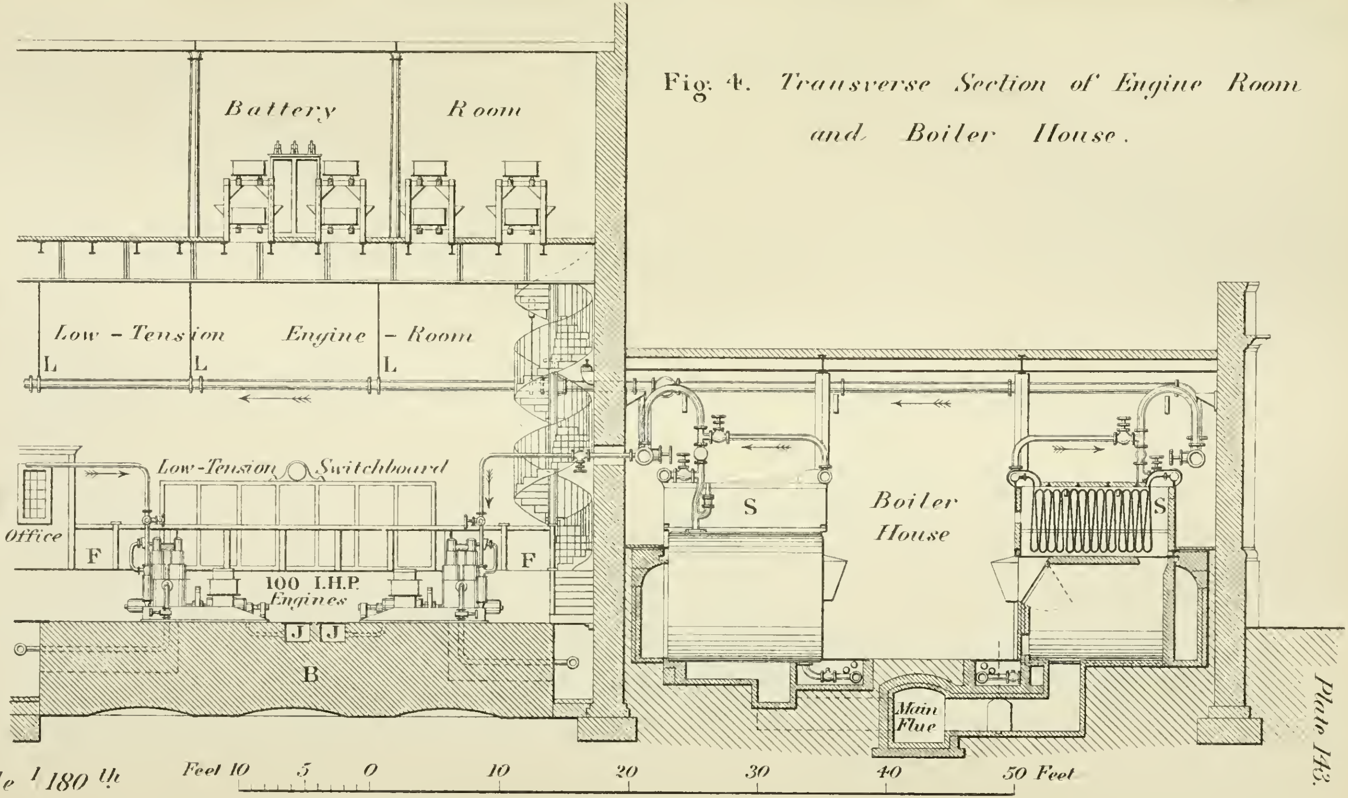


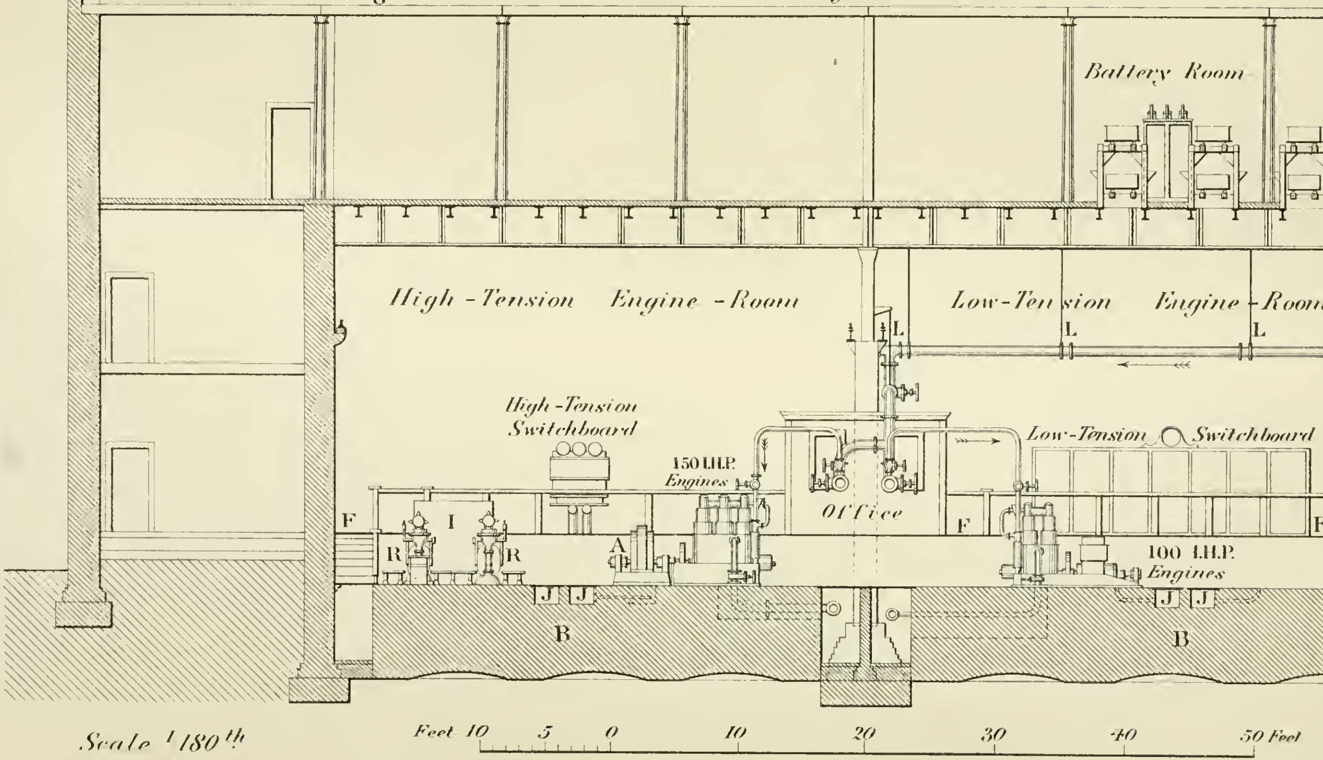
Fig. 4. Transverse Section of Engine Room and Boiler House.

See continuation in Plate 144.

Plate 143.

EDINBURGH ELECTRIC LIGHTING.

Fig: 5. *Transverse Section of Engine Rooms.*



Scale 1/180th

See continuation in Plate 143.

Plate 144.

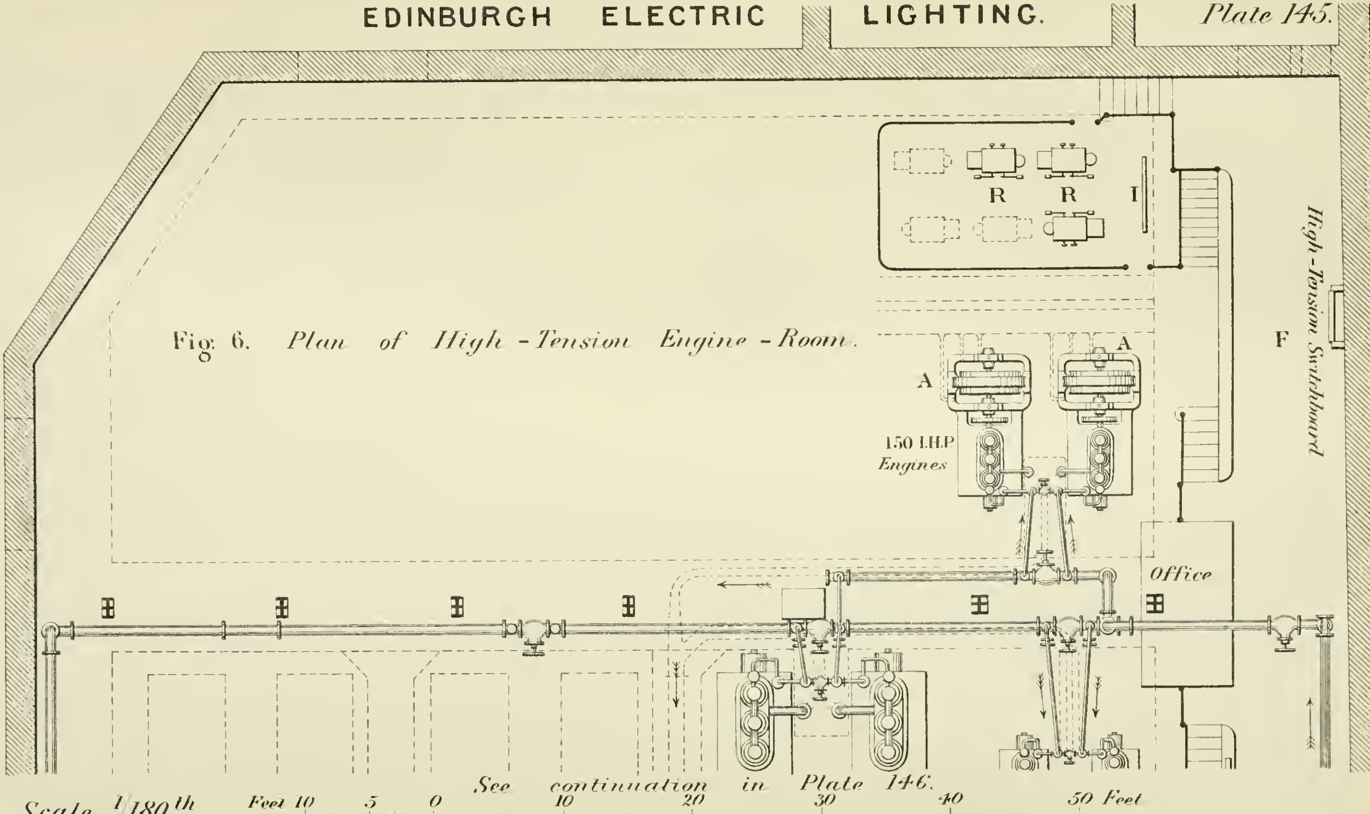


Fig. 6. *Plan of High-Tension Engine-Room.*

See continuation in Plate 146.

Scale 1/180th.

Plate 145.

EDINBURGH ELECTRIC LIGHTING.

See continuation in Plate 145.

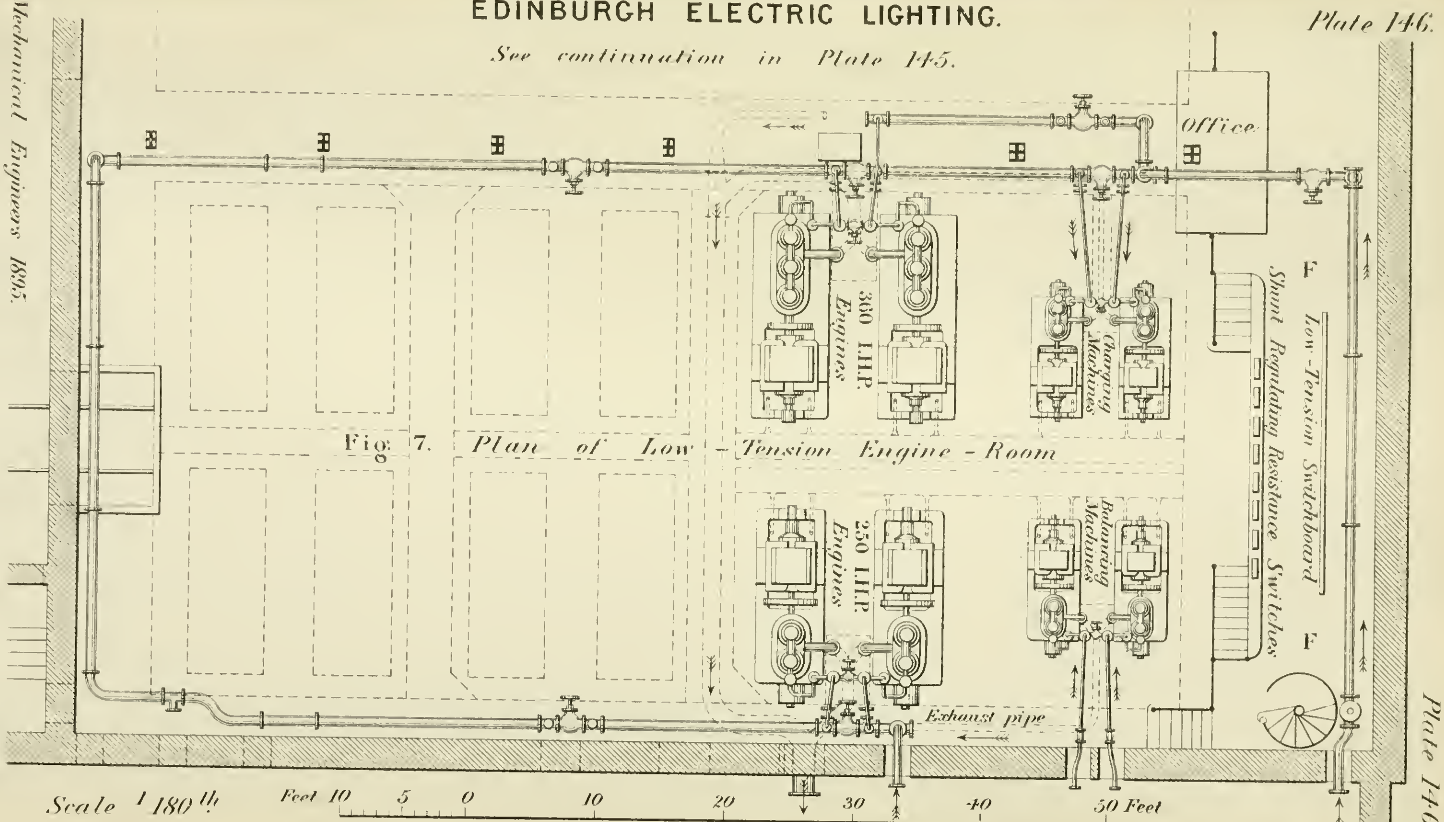


Fig. 7. Plan of Low-Tension Engine-Room

Plate 146.

EDINBURGH ELECTRIC LIGHTING.

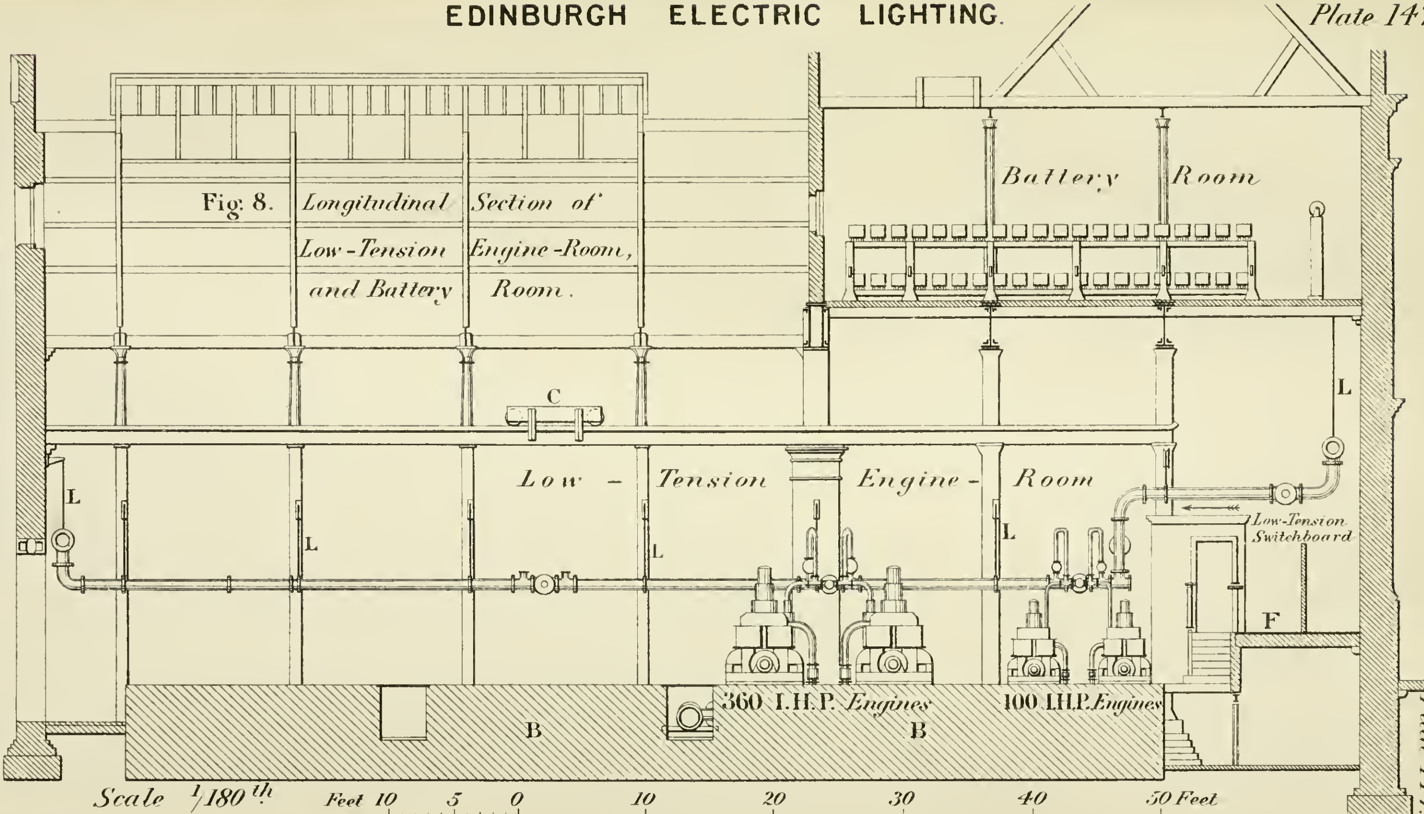


Fig. 8. Longitudinal Section of Low-Tension Engine-Room, and Battery Room.

Plate 147.

EDINBURGH ELECTRIC LIGHTING.

Fig. 9. *Switchboard connections.*

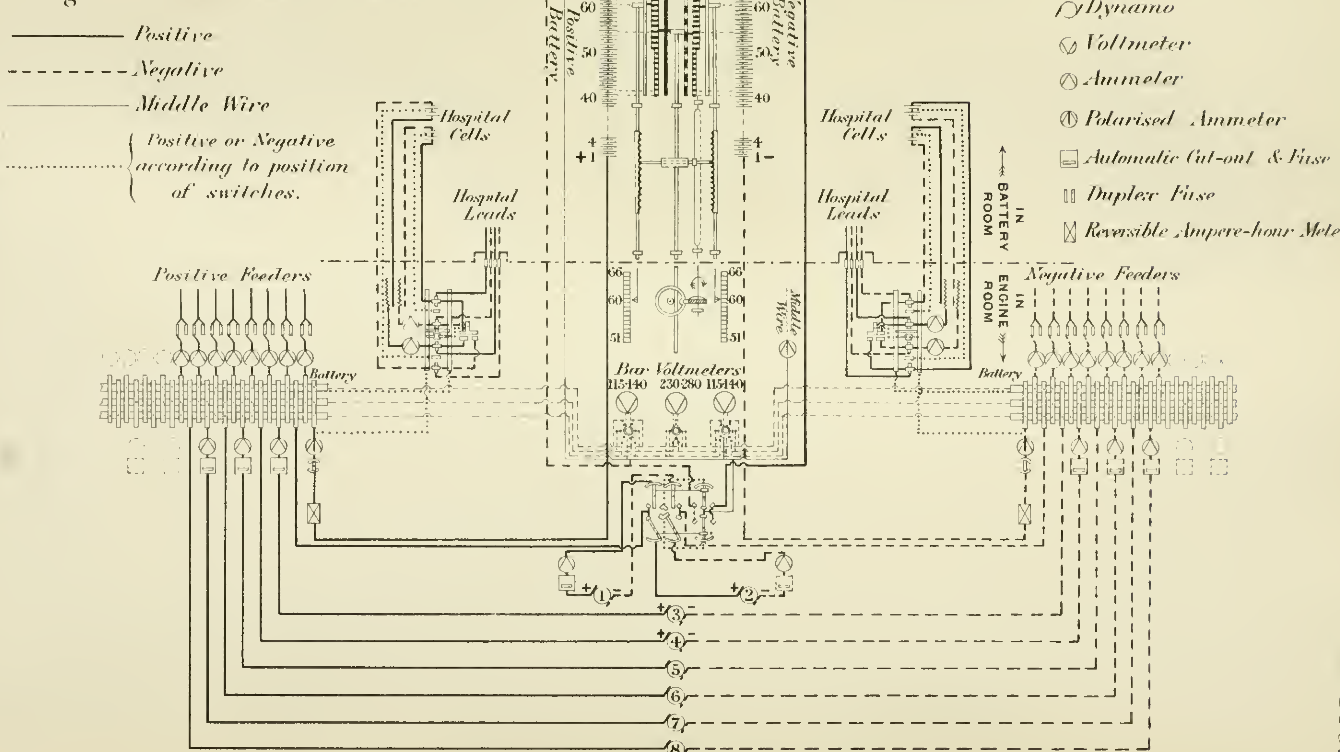


Plate 148.

Distributing Mains in Junction-Box.

Fig. 10. *Plan.*

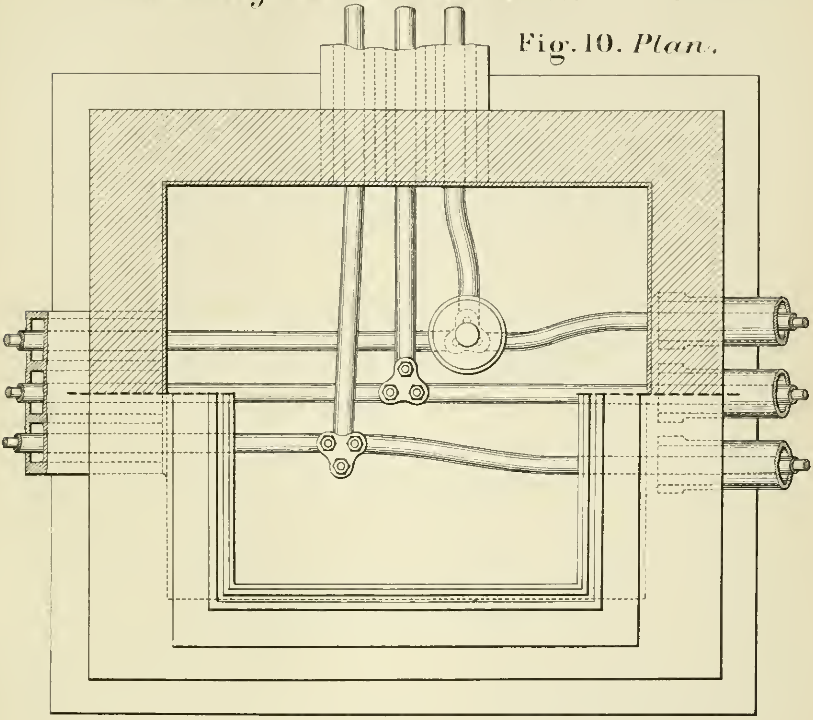
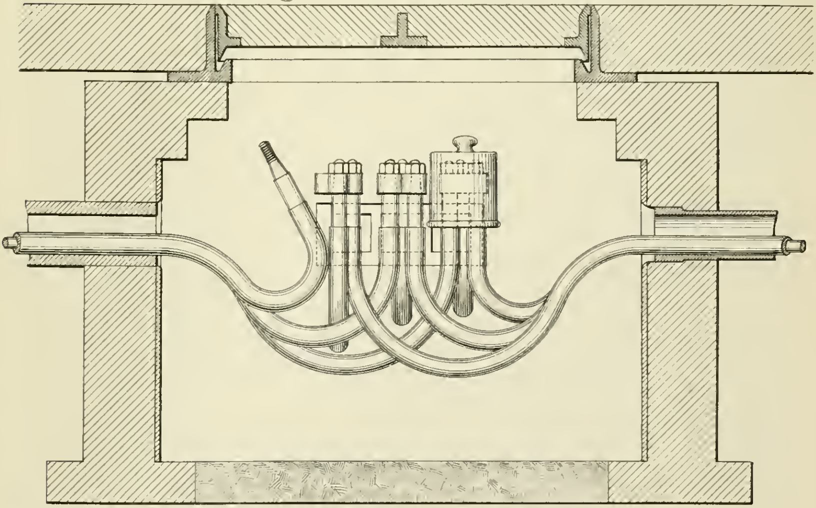


Fig. 11. *Vertical Section.*



Mechanical Engineers 1895. *Scale 1/12th.*

Inches 12 6 0 1 2 Feet

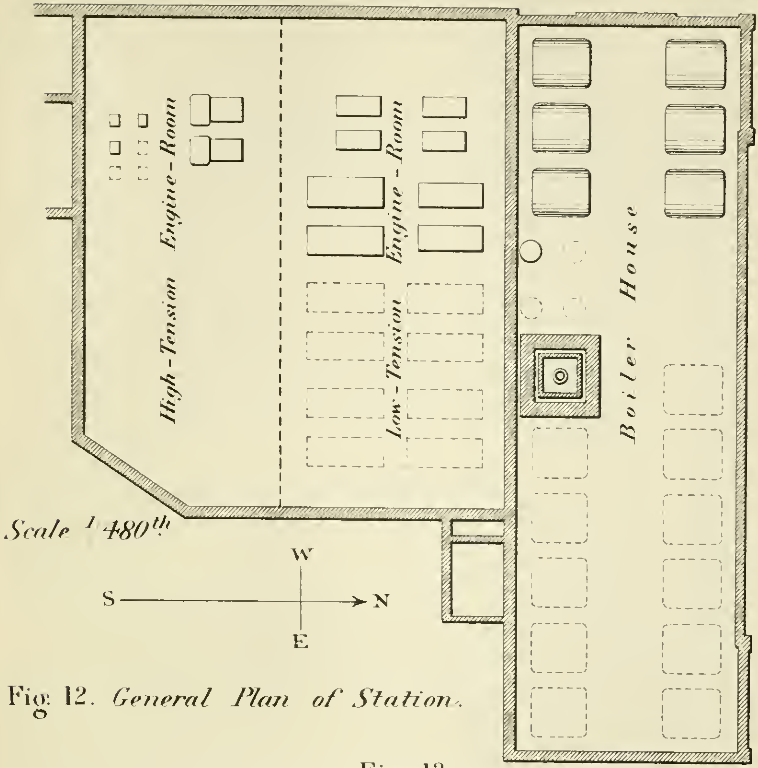


Fig. 12. *General Plan of Station.*

Fig. 13.

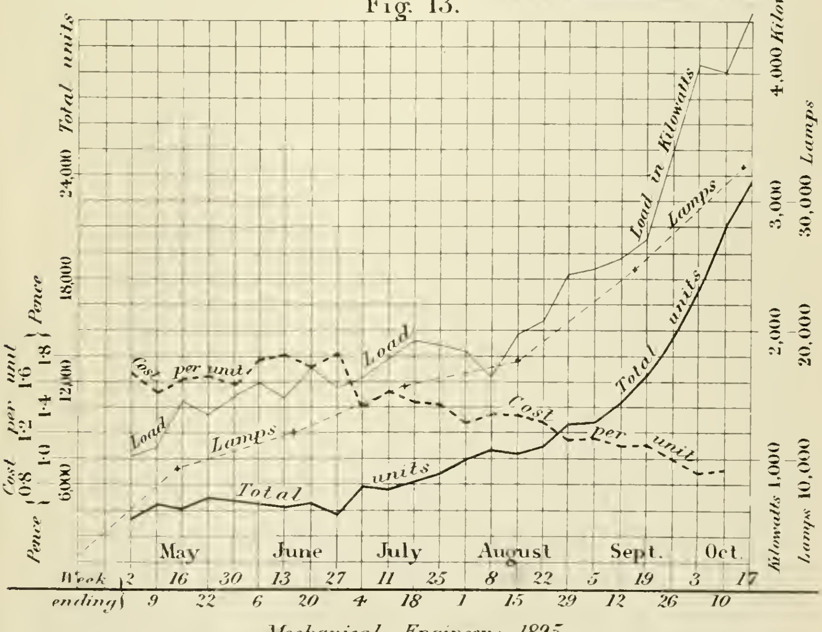
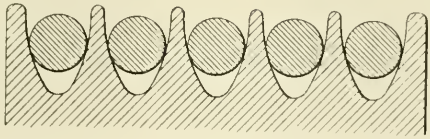
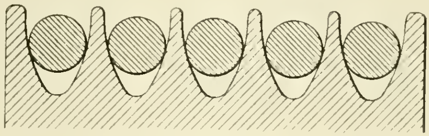


Fig: 1. *Rope Fly-wheel.*

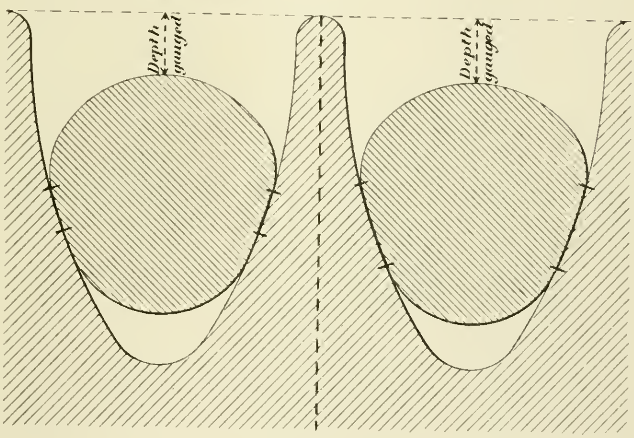


Scale 1/6th.

Fig: 2. *Rope Pulley.*

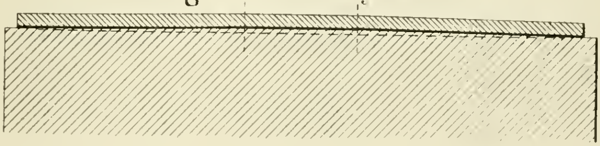


Fly-wheel. Fig: 3. *Pulley.*



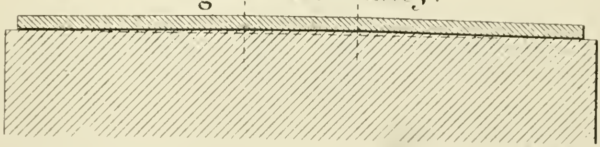
Scale 2/3rds.

Fig: 4. *Belt Fly-wheel.*



Scale 1/6th.

Fig: 5. *Belt Pulley.*



Mechanical Engineers 1895. *Scale 1/6th.*

0 5 10 15 Inches 20

Plate 152.

STRENGTH OF COPPER.

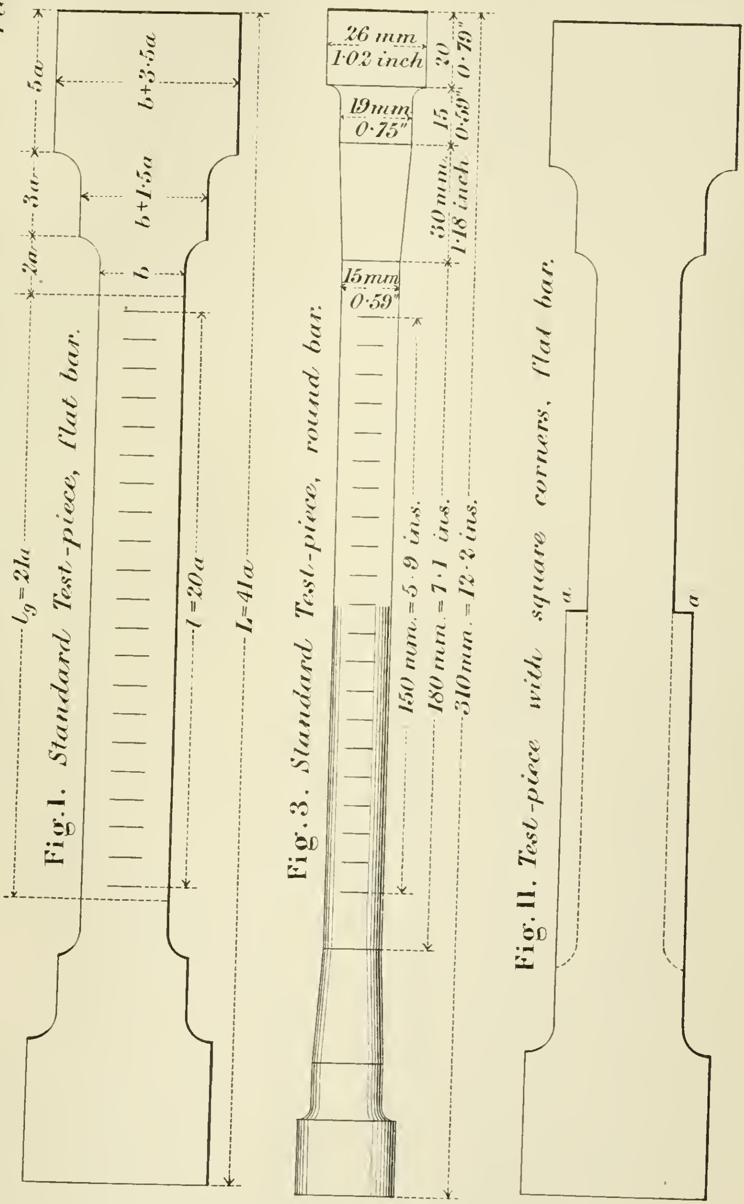


Fig. 1. Standard Test-piece, flat bar.

Fig. 3. Standard Test-piece, round bar.

Fig. 11. Test-piece with square corners, flat bar.

STRENGTH OF COPPER.

Fig. 43. *Standard Test-piece, round bar.*

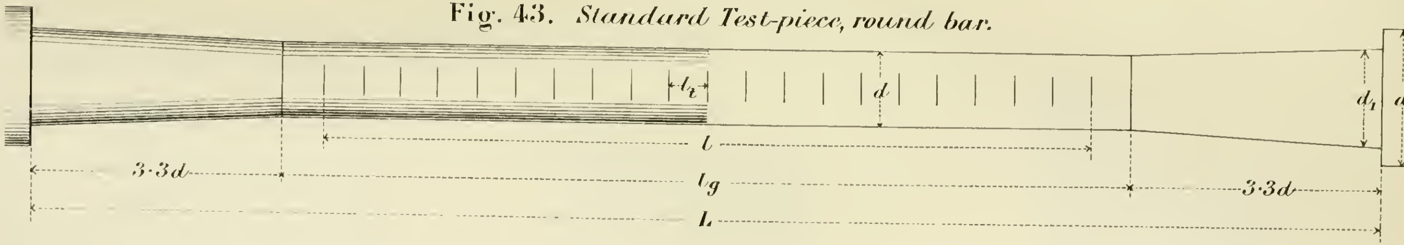
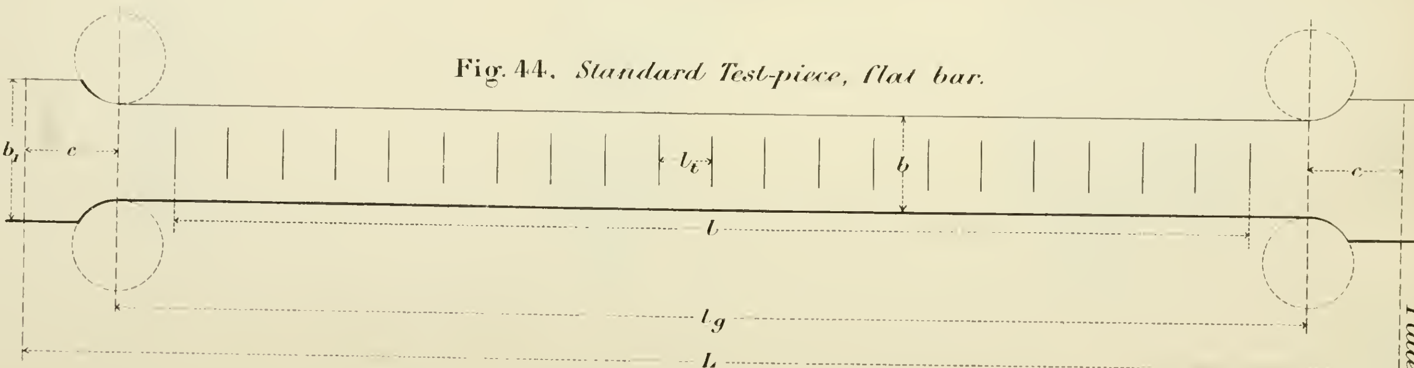


Fig. 44. *Standard Test-piece, flat bar.*



Mechanical Engineers 1895.

Plate 153.

Fig. 20.

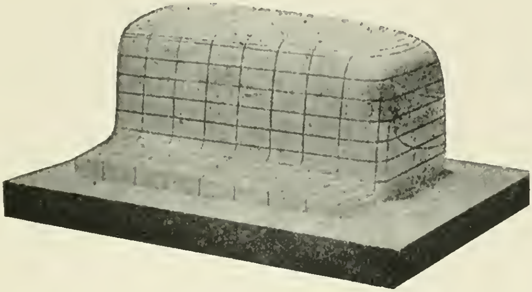


Fig. 73.

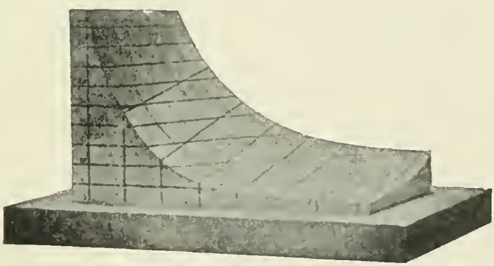


Fig. 74.